

**WORKS OF
JOSEPH H. SINCLAIR,
ROY J. COLONY,
THERON WASSON
and
CHARLES P. BERKEY
IN ECUADOR
1923-1932**



COMPILED BY STALYN PAUCAR

A COMPILATION OF THE WORKS OF
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EXPLORATIONS
IN
EASTERN ECUADOR

by

JOSEPH H. SINCLAIR

and

THERON WASSON

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INTRODUCTION

In the latter half of 1921, the writers were engaged in exploring a tract of 9600 square miles in that part of Ecuador lying east of the Andes to determine the possibilities for the eventual production of petroleum. The area was under concession by the Leonard Exploration Company of New York, through whose courtesy the publication of this paper is made possible.

This area is about one-fifth that of the state of Pennsylvania. Nothing was known of its geology, no mapping had ever been done, there were but a few muddy trails, and little knowledge was at hand regarding the climatic conditions. Four months were spent by us in traverses through the jungles on foot and in canoe. Our route, including some back-tracking, amounted to about 625 miles from the point of our departure at the end of the railroad, Pelileo, to our return at Riobamba.

THE JOURNEY INTO THE ORIENTE

From the Andean highlands the most convenient route into the eastern region of Ecuador, called the Oriente, is to leave the Guayaquil and Quito Railway at Ambato and descend the Río Pastaza. We first took the railway, known as the Ferrocarril al Curaray, from Ambato to Pelileo. Some 70 miles, of the proposed 180 miles, have been surveyed; but rails have been laid only as far as Pelileo, 21 miles east of Ambato. From this point we set out on horseback on August 11 and proceeded to Baños, situated two miles below the point where the Chambo and Patate Rivers unite to form the Pastaza at the base of the great volcano, Tunguragua. Baños is exactly 30 miles east of Ambato. We found it to be a town of about fifty houses with several hundred inhabitants. It is at an elevation of 6014 feet above sea level and just above the limits of the Amazon jungle. Baños owes its name to hot springs half a mile east of the village. About five miles below here the Pastaza passes over the famous Agoyán Falls, 198 feet high. The snow-capped peaks and glaciers of the watershed above this point furnish a constant supply of water, and it has been estimated¹ that 200000 horse power could be developed here. Continuing on horseback below the falls, we traveled on a trail notched into cliffs of schist and gneiss 1000 feet above the river, from which height it appears to be a roaring torrent 200 feet wide. Here and there high up the sides of the valley are hanging lateral valleys through which streams enter the Pastaza over falls. Altogether this is one of the wildest valleys imaginable.

Several miles below Baños we entered the Amazon jungle. We crossed the Río Verde by bridge, the Machay by a dangerous ford. At Quebrada San Francisco, 42 miles east of Ambato, we noticed sedimentary rocks for the first time. Similar rocks were seen at the Río Topo, 50 miles east of Ambato, where a bridge has been built. Shortly beyond the Topo we had to leave our horses, and our journey from there on was on foot. At Mera, 55 miles east of Ambato, at an elevation of 3800 feet, the Pastaza emerges from its great canyon. We found the village to consist of a string of about ten houses. It is in the belt of maximum rainfall.

¹ Moore C. H. (1914) Railway construction in Ecuador just south of the Equator. *Engineering News*, May 14, 1914. New York, pp. 1053-1057.

TRAVERSE TO THE RÍO ANZU

At Mera our survey started because we could tie our traverse to the survey of the Ferrocarril al Curaray which was run from the Guayaquil and Quito Railway at Ambato. Our method of surveying was as follows. We used a 300-foot length of linen tape treated with paraffin and employed a method used by us on the United States Geological Survey, orienting the traverse board by magnetic needle and then sighting to the voice of whoever was at the head or rear of the tape, taking elevations at each tape length with the aneroid barometer. This traverse was checked at controlling points by latitude observations made on stars with a precise transit. In connection with observations for latitude the true meridian was established at several points by transit observations on circumpolar stars or calculated from solar observations. The compass needle was then read on the established meridian. A Buff precise transit with a five-inch needle was used for this work.

From Mera we followed the Puyo trail across the Río Pindo Chico and, leaving this near Puyo, turned northeastward through the jungle to the Río Anzu. At the point where we first reached the Río Anzu it is about 160 feet wide, flowing in a bed of huge granite boulders. It is very swift and almost waist-deep with the characteristically crystal-clear water of the mountain streams to which Spruce² has made reference. We followed the bed for some distance to Embarcadero, 1780 feet in elevation, the head of canoe navigation, having traversed 36 miles through the jungle from Mera without seeing even an Indian hut. We arrived at Embarcadero on August 29 and descended by canoe 12 miles to the village of Napo on the Napo River. On all previous maps the Río Anzu has been shown as a small tributary of the Napo flowing into it from the west. Our survey showed it to be a much larger and longer river flowing parallel to the Andean chain from the south into the Napo.

The width of the valley of the Río Napo at Napo nearly coincides with the width of the stream, there being a steep hill on the south bank and only a narrow flood plain on the north bank from which the ascent is rather pronounced to the upland. It is on this narrow flat on the north bank of the river that the settlement of Napo is located at an elevation of 1680 feet above the sea.

THE SETTLEMENT OF NAPO

From the top of the cleared hill on the south bank of the river we looked west over an expanse of forested hills having an average elevation of 2000 feet above the sea. These rise gradually westward to about 4000 feet, where the wall of the Andes cuts them off. On a clear day a fine view is afforded of the snow-capped Andean Range from Antisana on the north to the great volcanic cone of Sangay on the south, a sweep of 120 miles.

² Richard Spruce: Notes of a Botanist on the Amazon and Andes, London, 1908; reference in Vol. 2, p. 146.

The settlement of Napo at the time of our visit was composed of three or four white Spanish-speaking families who have farms of a few acres each on the north bank of the river on which they raise cattle and horses and a few farm products, such as yuca, plantain, corn, and sugar cane, sufficient only for their own needs. Among these families is that of Sr. Manuel Rivadeneyra, who acted as our guide. Much of the success of the expedition was due to his knowledge of the country and his ability to hire Indian carriers. In Napo, as in other settlements of eastern Ecuador, no Indians are resident except as servants and laborers for the white families. They are to be found living on small clearings, hidden in the jungles along the streams where they raise yuca and plantain, fish a little, and also pan gold from the gravels along the bed of the river. Each white family has under its patronage a number of Indians whose gold is taken in exchange for cloth and other commodities obtained from Quito, an eight days' journey northward over a rough trail. We found the families at Napo to be remarkably intelligent, strong and healthy; but, as in the case of all pioneers, forced to depend on themselves in all emergencies. The children are educated at home, and there are no doctors or priests in the region.

The climatic conditions of Napo are very healthful. Temperature readings, taken during our stay from August 29 to September 23, 1921, show an average shade temperature of 77°F. The maximum recorded was 82°F, and the minimum in the daytime 66°F. At night, however, especially when it rains, it is much cooler, and covers are always needed in sleeping. We saw no mosquitoes and few other insects. The residents say that there is no malaria at all. Napo is not subjected to excessive rains as are such towns as Mera at the base of the Andes. The residents also informed us that the rains were somewhat greater in the other months of the year, which would indicate a cooler temperature in those months.

We spent twelve days in Napo making preparations for our trip down the river, taking latitude, longitude, and azimuth observations, and collecting fossils.

SURVEY OF THE RÍO NAPO FROM NAPO TO THE RÍO COCA

On September 5, with two canoes, we started a stadia traverse down the Napo. We used a rod 16 feet long, its feet divisions painted alternately black and white, and a 15-inch Gurley traverse table with a telescopic alidade, with which we were able to obtain sights of 3200 feet long by using one half the stadia interval. The river for 90 miles below Napo is characterized by numerous gravel bars so that we had no difficulty in finding rod and instrument stations.

TABLE 1 – TEMPERATURE READINGS AT NAPO (1850 FEET), 1921

Day	Hour	Temperature (° F)	
Aug. 29	6:00 P.M.	78.2	showers
Aug. 30	9:30 A.M.	77.7	fair
	noon	78.6	fair
Aug. 31	8:00 A.M.	79.7	rain
	noon	79.7	rain
	8:30 P.M.	79.3	rain
Sept. 1	8:00 A.M.	73.4	rain
	7:30 P.M.	66.2	rain
Sept. 2	11:00 A.M.	78.5	fair
	6:00 P.M.	77.8	fair
Sept. 3	8:00 P.M.	75.5	fair
Sept. 4	6:00 A.M.	78.0	fair
Sept. 21	8:00 P.M.	78.0	fair
Sept. 22	6:30 A.M.	73.0	fair
Sept. 23	9:00 A.M.	73.9	fair
?	7:00 A.M.	72.0	cloudy ?
	6:30 A.M.	68	cloudy
	7:20 A.M.	72	cloudy
	6:30 P.M.	77	cloudy
	9:00 A.M.	75	fair
	11:00 A.M.	78	fair
	11:30 A.M.	80	fair
	2:30 P.M.	82	fair
	3:30 P.M.	80	fair
	7:30 P.M.	78	fair
	8:30 P.M.	76	fair

The first settlement of white people below Napo is at Remolino de Latas, about five miles down the river, where one or two families live. Shortly below this point the river cuts through the contact of the limestones and shales with the overlying red clays and flows, for the rest of its course to the mouth of the Coca, through red beds and alluvium. The flats along the river here and in many other places consist of gravels 9 to 15 feet thick overlying the clays of the red beds. In places claims have been taken up by an Italian syndicate for gold dredging, but no machinery had arrived at the time of our visit. The next three settlements below Remolino de Latas are: Venecia, 7 miles below Napo on the left bank; a ranch on the left bank of the river 11 miles below Napo; and the cattle ranch of Umberto Garcias 17 miles below Napo. The last-mentioned consists of 290 acres of pasture land on the left bank and 125 acres on the right bank, the large ranch house having a beautiful location on the left bank. We were told the owner had 500 head of cattle, the market for which is far east on the Río Aguarico, a tributary of the Lower Napo.



Fig. 1 – The Pastaza River at Mera, 3800 feet above sea level where it emerges from its Andean canyon



Fig. 2 – The Napo River 44 miles below Napo. In the background is the Cordillera Galeras with summits about 6000 feet above sea level



Fig. 3 – The Napo River 80 miles below Napo



Fig. 4 – View from the station of the Dominican mission at Canelos across the Bobonaza River to the upland, over 3000 feet above sea level, between the Bobonaza and Pindo Rivers

On September 8, from our camp below the mouth of the Río Arajuno, we observed to the north a prominent mountain range which our guide informed us was the Cordillera Galeras. Thirty-one miles below Napo we passed the next settlement, Santa Rosa. Forty-four miles below Napo we observed a lofty, cone shaped peak, about 30 miles to the northwest, which we were told was named Sumaco. Vertical angles and intersections to this from several places on our traverse determined the exact location and gave its elevation as 12700 feet above the sea. Sumaco is beyond all questions the most remarkable physiographic feature we saw on the Amazon plain. We believe our expedition is the first accurately to locate it and obtain its elevation. Wolf says of this peak:

Outside of the Andean region of Ecuador there appears to exist a small volcanic area or perhaps an isolated volcano in the Oriente, in the upper part of the Napo basin; but no geologist has as yet studied it, and I can only describe rumors of its existence. Even the location of this volcano is not very sure³.

Humboldt does not show this volcanic peak, for such it probably is, on any of his maps; and Villavicencio, according to Wolf, shows such a mountain at a very great distance to the northeast of the Cordillera Guacamayo. Hamilton Rice⁴, describing his journey down the Napo River, refers to a cone-shaped peak called "Sumaco".

Two more ranches were passed, making seven in all on the banks of the Napo between Napo and the mouth of the Coca. Near the mouth of the Coca there is a settlement called Armenia, consisting of one or two houses. All the settlements along the Napo are occupied by pioneers of a high type. In addition, there are a few Indian families here and there along the river and doubtless others up the tributary streams.

From Napo to the mouth of the Río Coca is 97 miles by the river traverse. This stadia traverse of the Napo was later increased to a total of 120 miles by the stretch of 23 miles above Napo to the confluence of the Río Anzu, up this to the Río Ila, and up the Río Ila to the base of the Andes. It is the first accurate mapping ever made of the upper portion of the Napo. The nearest to this is a traverse of the lower Napo from Fortaleza, perhaps 60 miles below the mouth of the Coca, to the mouth of the Napo. This was probably a time survey by boat and thus very rough. The map ⁵shows no latitudes or longitudes. The stretch of river between Fortaleza and the mouth of the Río Coca leaves this travers entirely separated from our work.

³ Wolf Teodoro (1892) *Geografía y Geología del Ecuador*. Leipzig, p. 331.

⁴ Rice Hamilton (1901) From Quito to the Amazon via the River Napo. *Geogr. Journ.*, Vol. 21, pp. 401-418; Reference on p. 414.

⁵ Payer Richard (1894) Der Río Napo. *Petermanns Mitt.*, Vol. 40, pp. 169-171, with map „Originalkarte des Río Napo und Río Curaray“, scale 1:800000.

The Río Napo from Napo to the Río Coca is an excessively braided stream with numerous side channels of shallow depth. Orton ⁶in November, 1867, found the current of the Napo at Napo to be 6 miles an hour. Measurements by us on September 21, 1921, 60 miles below Napo, gave 5.5 miles an hour. At Napo the river is 300 feet wide and is deep with a swift current. It is subjected to sudden rises from rains in the mountains. At such times boulders can be heard grinding along the bottom. From Napo to Armenia, a distance of 86 miles, the river is characterized by a succession of rapids. The whites and Indians are experts in navigating these in dugout canoes. By poling upstream in the backwash close to the bank and by following side channels they are able to travel without difficulty. The river cannot be forded at Napo nor at any point in the hundred miles to the Río Coca. The bottom is rocky and the water clear to about 11 miles above the mouth of the Coca, where a striking change takes place. Islands disappear, mud banks appear; the river has but one channel one-quarter mile wide with sluggish current, muddy water after rains, and a depth sufficient for small steamers. This change may be considered as marking the “fall line”, a characteristic of all rivers of eastern Ecuador. The mouth of the Coca is 850 feet above sea level, and the Napo at this point is 2000 feet across. The Coca is distant 400 miles from the mouth of the Napo, which enters the Amazon below Iquitos, a port for ocean steamers with a draft of 20 feet. The maximum cargo we know to have been poled up as far as Napo was a grand piano, moved by a former governor from Iquitos to Tena, where it is now in use. The return from the mouth of the Río Coca to Napo took us seven days, an average of 14 miles a day of poling. We had six Indians at work nine hours a day.



Fig. 5 – Mt. Sumaco (12700 feet) seen from Archidona, from which point it lies 28 miles to the north-northeast. The exact position of this isolated peak, probably a volcano, was determined for the first time by the writers' expedition

⁶ Orton James (1870) *The Andes and the Amazon*. New York.

FROM NAPO TO ARCHIDONA ON THE PAPALLACTA TRAIL

The Papallacta Trail is one of the old routes from Quito to the Amazon plain⁷. We mapped 25 miles of it between Napo and the base of the Cordillera Guacamayo.

From Napo to Tena the trail can be negotiated by horses, which by painful experiences have learned to jump across mud holes or plow through them. The trail ascends gradually from Napo, 1680 feet above the sea, to an upland of fairly smooth surface which, between Napo and Tena, is at a maximum of 1950 feet above the sea, 300 feet above the valley bottoms.

TABLE II – TEMPERATURE READINGS AT ARCHIDONA (2000 FEET), 1921

Day	Hour	Temperature (° F)	
Sept. 26	3:15 P.M.	82.0	fair
	4:00 P.M.	76.8	showers
Sept. 27	7:00 A.M.	72.3	fair
Oct. 1	7:00 A.M.	68.7	fair
Oct. 7	noon	78.0	showers
	7:00 P.M.	77.0	fair
Oct. 8	6:30 A.M.	67.4	fair

This is underlain by nearly horizontal limestones. In places on this upland, remnants of the red beds are seen overlying the limestones. Both the limestones and red beds are in places covered by thin deposits of volcanic débris. One white family is found on the trail from Napo to Tena, the house occupying the only clearing in the five miles between these two points. Tena is the capital of the Oriente and the residence of the present governor, whose courtesy toward us helped make our expedition a success. Tena, 1700 feet in elevation, lies on the left bank of the Río Tena, an easily fordable stream, a mile above its entry into the Río Misahuallí. The settlement is surrounded by clearings where cattle graze and crops are raised, and about half a dozen white families reside here. The Indians live, as usual, scattered in the neighboring jungle along the stream banks. Dr. Jameson, who visited Tena in 1857, described it as having been recently built⁸.

The Río Misahuallí, below the mouth of the Tena and below its tributary, the Río Hollín, flows in a narrow canyon with precipitous walls. We descended the Río Misahuallí by canoe to a mile below the entry of the Hollín about six miles below Tena. Below this point it has never been descended, as the canyon narrows and the river is full of impassable rapids.

⁷ For a description of this trail see Manuel Villavicencio (1858) *Geografía de la República del Ecuador*. New York, p. 138.

⁸ Jameson William (1858) Excursion made from Quito to the River Napo, January to May, 1857. *Journ. Royal Geogr. Soc.*, Vol. 28, 1858, pp. 337-349; Reference on p. 341.

On the Papallacta Trail six and a half miles north of Tena and on the left bank of the Río Misahuallí is Archidona, at an elevation of 2000 feet. This is one of the several "towns" founded in the Ecuadorian montaña in the mid-sixteenth century. For a long time, according to Villavicencio, it was the key to the Jesuit missions of the Marañón. In 1858 he describes it as having, besides the mission, no white resident but about 300 Indians residing near by in the forest. Today, however, there is no longer a mission station here, nor at Tena, nor at Napo. Archidona consists of four or five white families in as many houses arranged about a public square. Back of the houses and along the Quito trail are cleared pastures which make it a pleasant spot. The summits of the Andean Range dominate the view to the west of Archidona, and to the north rises the Cordillera Guacamayo. But the most striking mountain feature to be seen from Archidona is the great isolated cone of Sumaco, 28 miles to the north-northeast.

On October 1 we left Archidona on horseback by the Papallacta Trail and turned aside four miles north to follow on foot a newly cut trail eastward to the Río Jandachi. The Jandachi we found to be a roaring torrent, 50 feet wide, occupying a narrow canyon, sunk to a depth of about 735 feet below the upland surface. We saw this stream again some miles farther north at the base of the Cordillera Guacamayo. The surface between Napo and the Cordillera Guacamayo is in general a dissected plateau rising in elevation from 2000 to 4000 feet at its contact with the wall of the Cordillera Guacamayo. A striking feature of the plateau surface is the presence of huge granite blocks, often as large as a house, lying on perfectly undisturbed sedimentary rocks. These may be erratics of glacial origin. The rocks of the plateau on the south side of the Jandachi valley terminate abruptly and without disturbance against the old granitic core of the Cordillera Guacamayo which rises to about 8000 feet above the sea. Further study will be necessary to work out the relations of the Cordillera Guacamayo, the Cordillera Galeras, and Mt. Sumaco to the surrounding sedimentary rocks. It is probable that the Cordillera Guacamayo is composed of granite and schist and is an offshoot of the Eastern Cordillera, the fault line of the Andes here making a salient to the east.

We did not ascend the Cordillera Guacamayo but returned the 26 miles to Napo and on October 17 started poling up the Napo and Anzu Rivers to Embarcadero, the terminus of our trail from Mera, and head of canoe navigation. From Embarcadero we traversed a short distance up the Río Ila to a point where the red beds disappear beneath a basaltic lava flow near the base of the Eastern Cordillera of the Andes. This is a very interesting locality on account of the absence of disturbance or metamorphism in the red beds right up to the contact. This, together with the horizontal position of the limestones at the base of the Cordillera Guacamayo, is very striking and in sharp contrast to the contact on the western side of the Andes.



Fig. 6 – House of one of the settlers at Napo



Fig. 7 – Indians of Canelos in front of the Dominican mission house at Canelos

SURVEY FROM NAPO TO CANELOS

The usual route from Napo to Canelos is by an old Indian trail to Puyo and thence via Indelyama to Canelos. We felt it necessary, however, to study the geological structure east of this route and decided to attempt a traverse through the jungle, although warned of dangerous Indians and the lack of a trail. On October 27 we left Napo, striking southeast. The surface is more dissected into sharp hills and ridges and has more streams than north of Napo. The first large stream encountered was the Puni-yacu which, although 150 feet wide, was shallow enough for us to ford. We reached the Río Arajuno at a point where it is 200 feet wide. This, like the Napo, is divided into many branches and has a swift current of very clear water. We continued the traverse by stadia for some distance up the river bed, camping on October 29 at an Indian's hut. On November 1 we reached the Río Curaray. The upland surface between the two rivers attains a maximum of 2040 feet above the sea and is well forested. The Curaray River is a winding, shallow creek about 30 feet wide and, where we left it, is 1815 feet above the sea. At one place on the river we found the ruins of an old Jesuit mission, only another indication that the upper Curaray, like much of the Oriente, at one time supported a larger population than at present. The interstream area between the Curaray and the next river south, the Río Villano, is six miles wide, and the divide attains summits 2820 feet above the sea. We crossed the divide on November 5 and camped on the Río Villano at an Indian hut 1740 feet above the sea. On November 6, crossing another upland of 2390 feet maximum elevation, we proceeded 12 miles to Canelos along the Río Bobonaza. The 50 miles through the forest was without trail, and a large part of the journey consisted of wading in streams. Only three Indian huts were seen in all this distance.

We found Canelos to consist of the residence and church of the Dominican Mission; a house used by a government official, vacant at the time of our visit; and the house of a white settler who has lived here with his family for many years. There were three priests at the mission, and while we were at Canelos a fourth arrived from Puyo. The mission, which has been maintained with periods of abandonment for at least 200 years, consists of two large, substantial buildings having red tile roofs – the finest buildings we saw in the Oriente. Father Leon, the present head of the mission, has been there 30 years. Canelos is situated on a beautiful plain overlooking the Río Bobonaza at an elevation of 1690 feet above sea level. The settlement is surrounded by pastures and farms where one of the priests who is a farmer has fine cattle and raises excellent vegetables with which we were generously supplied. There are few mosquitoes and no malaria. During our stay the average daytime temperature was 75°F. with a maximum of 81° and a minimum of 68°. The small range of temperature is a striking characteristic of this entire country. Canelos is important as the terminus of one of the important land routes from Ambato via Baños, Mera, and Puyo to the Oriente; for here the Bobonaza becomes navigable, and canoes in ten days can reach the Pastaza at Andoas, head of navigation on that stream. The reason for crossing from Puyo on the Pastaza River to the Bobonaza is that the Río Pastaza is not navigable for canoes for many miles below Puyo.

TABLE III – TEMPERATURE READINGS AT CANELOS (1690 FEET), 1921

Day	Hour	Temperature (° F)	
Nov. 9	3:00 P.M.	76.1	fair
Nov. 10	7:15 A.M.	68.0	cloudy
	8:15 A.M.	70.0	cloudy
	10:15 A.M.	72.0	cloudy
	noon	77.0	cloudy
	1:00 P.M.	78.0	cloudy
	2:15 P.M.	81.0	cloudy
	3:30 P.M.	81.0	cloudy
	6:00 P.M.	80.0	cloudy
	7:30 P.M.	76.0	cloudy
	8:30 P.M.	75.0	cloudy
Nov. 11	8:30 A.M.	72.0	fair
	10:00 A.M.	76.0	fair
	11:00 A.M.	80.0	fair
	4:00 P.M.	82.0	fair
	6:30 P.M.	80.0	fair
	10:30 P.M.	78.0	fair
	1:00 P.M.	70.0	fair
Nov. 12	6:30 A.M.	76.0	fair
	8:30 A.M.	68.0	cloudy, rain
	9:30 A.M.	67.0	cloudy, rain
	1:00 P.M.	72.0	cloudy, rain
	3:00 P.M.	73.0	fair

SURVEY FROM CANELOS TO ALAPICOS

Thanks to the assistance of the Dominican Fathers we secured Indians to carry our packs and left Canelos on November 13 to survey the trail to Alapicos on the Río Palora, a tributary of the Pastaza. We followed the Puyo trail for 12 miles to Indelyama, which consists of one or two Indian huts on the left bank of the Río Pindo. At Indelyama the Pindo is 50 feet wide, about two feet deep, and very swift. Here we obtained two canoes and made a stadia traverse of the Río Pindo to its confluence with the Río Pastaza, a distance of about five miles. It proved to be a dangerous stream for canoeing on account of the bad rapids. The recently opened trail which follows the left bank should be used by all means.

The Pastaza at the mouth of the Pindo is divided into two channels, each 300 feet wide, separated by an island 1900 feet wide at low water. The river is not navigable for many miles below this point; certainly the point of navigation would be well below the mouth of the Palora. The grade of the Pastaza between Ambato (8100 feet) and the mouth of the Alpa-yacu just below Mera (3800 feet), where the Pastaza comes out on to the Amazon plain, is one per cent, or 52.8 feet in the mile; between Mera and the mouth of the Pindo the grade is about 40 feet in the mile.

TABLE IV – TEMPERATURE READINGS AT ALAPICOS (3080 FEET), 1921

Day	Hour	Temperature (° F)	
Nov. 20	3:15 P.M.	65.0	rain
	4:00 P.M.	65.0	rain
	5:10 P.M.	64.0	rain
Nov. 21	6:00 A.M.	62.6	clear
	7:00 A.M.	63.5	clear
	Noon	80.0	clear
Nov. 22	6.30 A.M.	68.0	fair
	1:15 P.M.	76.1	fair

From the Pastaza to Alapicos the distance is 13 miles by trail, a large part of which is through water on account of the extraordinary number of small streams, the smallest of which is knee deep and 10 feet wide. Alapicos is on the left bank of the Río Palora at an elevation of 3080 feet and consists of one white Spanish-speaking family and a mission residence and church. There were no priests there at the time of our visit. The Indians in the vicinity are Jíbaros⁹, the Pastaza River being the boundary between these tribes and those speaking the Quechua language.

The dominating feature of the landscape at Alapicos is the great volcanic cone Sangay, 28 miles west, rising to an elevation of nearly 17500 feet, with 2000 feet of its cone covered with perpetual snow. Of all the volcanic cones of the Andes seen by us Sangay stood first for perfection of form.

On November 23 we obtained canoes and crossed the Río Palora, which is 300 feet wide and has a terrific current even at low water. Thence a traverse of 35 miles brought us to Macas. Our route lay across a jungle-covered, smooth-surfaced plateau of volcanic agglomerate. We passed three Jíbaro settlements, one of which consisted of four huts. In one of these the head of a woman was being reduced in accordance with the terrible practice engaged in by the people.



Fig. 8 – The volcano Sangay (17459 feet) seen from Macas at a distance of 26 miles. Wolf described Sangay as one of the most active of the world's volcanoes

⁹ On the Jíbaros see Hermessen J. L. (1917) A Journey on the Río Zamora, Ecuador. *Geogr. Rev.* Vol. 4, pp. 434-449.

MACAS, CHIEF TOWN OF THE ORIENTE

Macas is a town of about 500 white people, the largest of the Oriente. It is situated on the south bank of the Upano River on a volcanic plain some 150 feet above the river bed, at an elevation of 3580 feet. It is several miles east of the base of the Cordillera Oriental, out of which the Upano emerges through a great canyon. Each house is in the center of a little farm. Owing to the fertility of the volcanic soil a large variety of foodstuffs is grown, and the region is famed for its magnificent cattle for which, however, there is no market. Macas, like the other towns, is exceptionally healthful; for there are no mosquitoes, the water supply is pure, and it is probable that the mean yearly temperature does not exceed 72°F. We were favored by a visit from the school children of Macas on the day after our arrival and were impressed by their intelligent faces, cleanliness, and healthiness. The Comandante, Sr. Manuel J. Bejarano, and his secretary made us welcome and gave us rooms in the house formerly occupied by Dominican priests. They assisted us in getting cargo carriers for the trip to Riobamba.

Across the river from Macas is the -probable site of Sevilla de Oro, one of the famous montaña towns of the sixteenth century, of which today nothing remains except the mythical tales of its greatness. It is said that in the early days the Spaniards had a horseback trail all the way to Macas from Riobamba on the Andean plateau, but today horses can be ridden from Riobamba only as far as Chanala, just east of the summit of the Andes, and should be taken only as far as the lakes at the head of the Upano River. The rest of the journey demands several days of wallowing in mud and of ascending and descending high ridges.



Fig. 9 – A fine example of a braided stream. Looking up the Upano River from Macas (3580 feet). The stream bed is cut in a volcanic plain

On December 2 we left Macas by the Upano Trail which, after following a swamp for a few miles, climbs up and down a succession of steep ridges. At times the trail narrows to a trench hardly wide enough for a man to pass through and is knee-deep in mud, with vertical walls 15 feet high, the result of many years of use and no repairs. On the fourth day of walking we reached the village of Chanala (8298 feet), the first settlement west of Macas, where about 20 whites and Indians live. Thence crossing over a pass 10000 feet above the sea we reached the village of Zunac (9052 feet), occupied part of the year by the inhabitants of Chanala but deserted at the time of our arrival. Shortly beyond Zunac we finally emerged from the Amazon jungle at the foot of lofty cliffs up which two hours of climbing brought us to two lakes, Colay and Mocatlan, 12000 feet above sea level, situated on the treeless *páramo*. We were at last on top of the Andes with snow-capped peaks about us. From this point we descended on horseback the Chambo valley to Riobamba, the end of our journey.

SUMMARY OF TOPOGRAPHY

Some of the outstanding facts of the foregoing description may be briefly summarized.

In the Oriente the Amazon plain abuts abruptly against the base of the Eastern Cordillera of the Andes at elevations of 3800 feet near Mera, 3600 feet at Macas, 4100 feet at the base of the Cordillera Guacamayo – in general 4000 feet above sea level. Thence it slopes gently eastward, descending in a distance of 70 miles to a surface about 1000 feet above the sea at the mouth of the Río Coca. Only a few relief features break the evenness of this surface: the Cordillera Guacamayo in the north with summits about 9000 feet above the sea; the Cordillera Galeras north of the Río Napo, probably a residual range, whose summits reach 6000 feet; and, most striking feature of all, Mt. Sumaco, the great cone-shaped peak east of the Cordillera Guacamayo whose summit is 12700 feet. The valleys have a maximum depth below the upper surface of 1000 feet, with interstream areas several miles wide. The rivers are all swift, torrential streams, navigable, if at all, only for Indian canoes, until they change to deep, sluggish, wide, muddy streams navigable for small steamers.

CLIMATE

The limited time spent by us in the Oriente – four months, August to November – does not permit the formation of conclusions regarding climatic conditions through the year. It may be remarked, however, that temperature in the Oriente has a very small range, daily and annually. Rainfall, as well as altitude, affects the temperature, districts like Mera in the belt of maximum rainfall being cooler than corresponding elevations farther east.



Fig. 10 – Andean lakes 12000 feet above sea level: that in the background is the source of the Chambo River, affluent of the Pastaza, that in the foreground of the Upano River



Fig. 11 – Meanders in the Chambo valley. Typical *páramo* country, elevation over 11000 feet

There is a pronounced difference in the rainfall in the Oriente. The trades coming from the southeast are drying as they ascend the Río Napo, but upon reaching the wall of the Andes and rising suddenly from 4000 to 18000 feet they are suddenly cooled and give up their moisture. The belt of maximum precipitation in the region described in this paper lies approximately between the levels of Mera (3800 feet) and Baños (6000 feet) where it rains nearly every day. Below 4000 feet the rains were moderate at the time of our visit. It is reported that the months of September and November are the driest of the year. We have no records of actual rainfall in the Oriente except for Puyo, a few miles east of Mera, i.e. close to the belt of maximum rainfall at 3200 feet elevation. Martínez gives the following record for four months, year not stated: December, 8.7 inches; January, 12 inches; February, 18.4 inches; March, 13.7 inches. The annual total on the basis of these figures would amount to 150 inches. It is not surprising that there are fewer Indians living in the vicinity of Mera than eastward in the drier region about Canelos and Napo.

It was noted early in our work that barometric changes were very constant. Humboldt was the first to call attention to the uniform variation of atmospheric pressure in the equatorial regions of South America. He said that the time of day could be told by a barometric reading. High barometer is found at nine in the morning and low barometer at four in the afternoon. This was true every day regardless of the weather. However, when the pressures for several days have been plotted, the curve for a clear day will be approximately parallel with but above the curve for a rainy day. Nearly every day the afternoon low barometer was followed by rain which often lasted into the evening. Our barometric observations were taken in feet of elevation and were plotted showing the variation at Napo, Canelos, Alapicos, Macas, and intermediary points. These curves were very similar, and, after finding the law of variation, a correction table was made which was used throughout the survey whenever elevations were recorded.

MAGNETIC DECLINATION

At all important stations the magnetic declination was determined. In every case the compass needle pointed east of the true meridian. The declination for the chief localities was thus: Napo, 5°43' E.; Tena, 5°43' E.; Canelos, 5°45' E.; Alapicos, 6°14' E.; Macas, 6°19' E.

ANIMAL LIFE IN THE JUNGLE

While the purposes of the expedition were essentially geological and geographical, some notes may be made on the wild life of the region. While descending the Pastaza from Baños to Mera heavy rains prevented us from seeing more than an occasional bird. On the trail from Mera to Napo we first saw tracks of the tapir, which is the largest animal in this region. Around one of the camps at night a crashing of small trees and branches was heard. Inquiry among the carriers brought forth the information that a herd of tapirs was passing. Our first glimpse of this creature was when the Indians chased one into the Río Napo below Venecia and speared it with wooden lances. They were so anxious to get at the meat that in a few minutes they had the carcass dismembered on the beach. It was as large as a small horse, probably weighing over one thousand pounds. The Indians gave us one of the quarters, but we found the meat tough. They, however, had a great feast on it. Tapir trails which we saw later were always in bottom lands near streams.

Deer tracks were observed throughout the region, and an animal was occasionally seen. They were dull gray in color and of good size. So much noise was made in the progress of our survey that it was impossible to get near them. This was true of many other animals. We saw the tracks and wallows of wild hogs but never came upon the animals. They are hunted by whites and Indians for their meat.

Two river animals which we saw were called by the natives *huanta* and *huatusa*. They are three-toed, tailless rodents with small front legs and powerful hind legs. The *huanta* is the larger, weighing fifty pounds or more, while the *huatusa* averages ten or fifteen pounds. Both are prized for their meat.

The one species of monkey encountered had a smooth black face and dark red fur and averaged perhaps thirty pounds in weight. We saw them first along the Anzu River above Napo and again on the trail from Napo to Canelos. The Indians and whites hunt them for food.

Our Indians shot two tree sloths near Canelos. They were shaggy, gray-green animals slightly heavier than the monkeys. They live entirely in the trees and because of their protective coloring and slow motions are not easily detected. Their green coloring is due to an organism which grows on the hair.

Another tree animal, the night-foraging honey bear or night monkey of the natives, was present around all our camps. His sharp, little, squeaky whistle was heard many nights before we learned the identity of the visitor. Our friends at Archidona gave us one which was quite tame. His sharp nose and long, ringed tail made him appear like the raccoon of our northern forests. The natives at Alapicos gave us the skin of an ant-eater, or ant-eating bear, which in size and color was like a small black bear. It has a long bushy tail of coarse excelsior-like hair.

Skins of jaguars, some of large size, were shown us in the towns; but we saw only an occasional track along the trail. The Indians of our party feared the "tigers", as they called them. It is probable that they are the most ferocious animals in the region.

Bats were common, and we slept under nets more as a protection from them than from mosquitoes. We saw horses and cattle which had been bitten by the vampire bat.

The Indians talked of snakes, particularly the water boa which haunts the rivers further east; but in our travels we saw none.

We were impressed by the almost total absence of birds from great jungle areas; day after day we traversed the trails seeing only a stray humming bird or hearing a pair of parrots scolding as they passed overhead. A kingfisher with a dull, orange breast was seen along the rivers, just as industrious and just as clattering as his northern brother. Toucans were sometimes seen in the jungle and around native houses, where they are kept as pets. Wild turkeys live along the smaller streams. On the lower Napo we saw a few condors. The Jíbaros around Macas showed us many small, highly colored birds which they shoot with blowguns. Most of these resemble orioles or finches. At Macas we saw for the first time swallows with black crosses on the under sides of their wings.

POPULATION

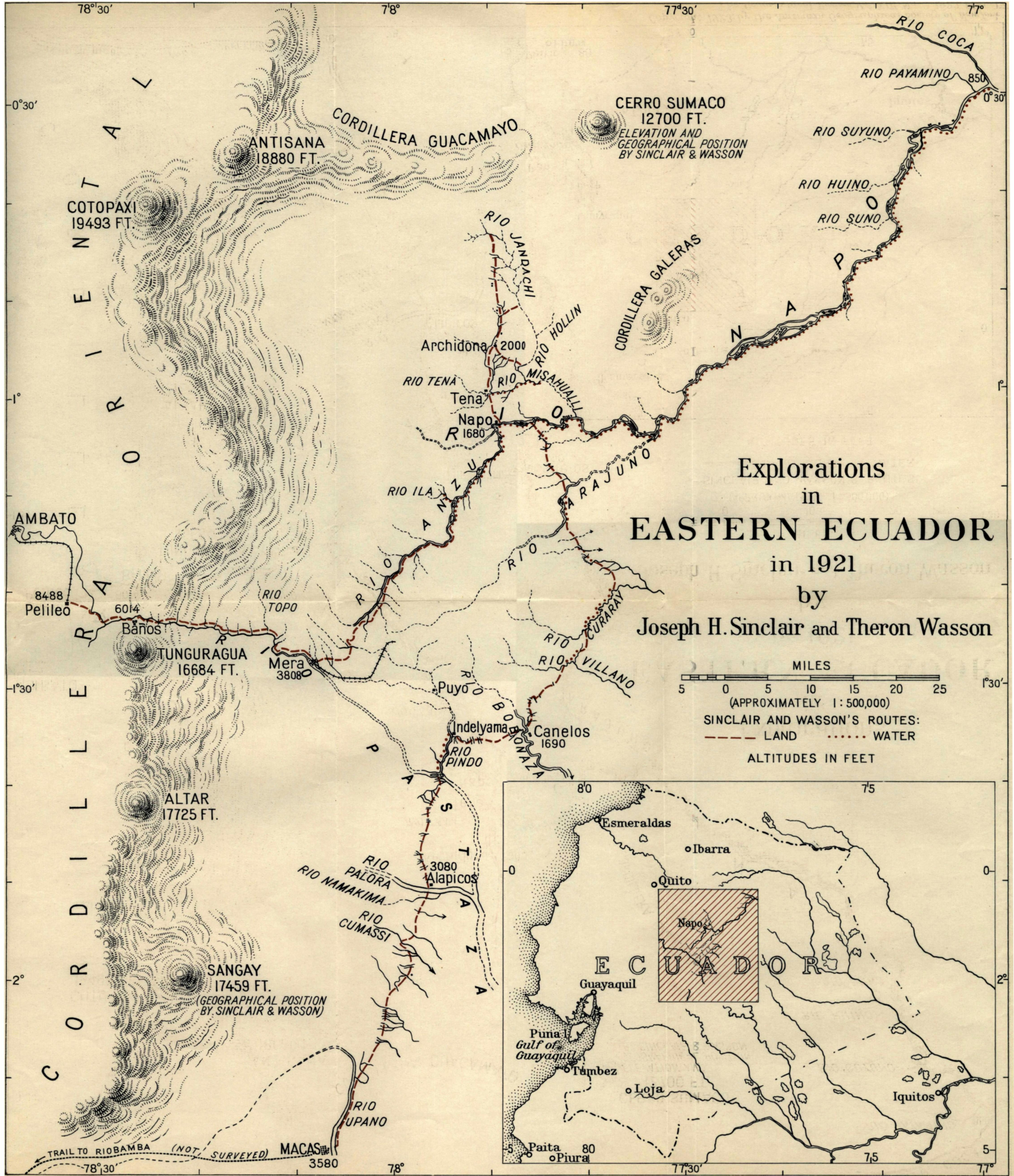
The Pastaza River is the dividing line between Indian tribes who speak different languages. The Quechua-speaking Indians live north of the river and are known as “Napo” Indians, “Canelos” Indians, etc., according to the name of the white settlement near which they reside. A characteristic of these Indians, as well as of the Jíbaros further south, is the fact that they have no villages. They live along streams, each family separated from the next. Near the white settlements, however, their huts, while continuing to be hidden in the jungle, are closer together. At Canelos, for example, the village consists of two or three houses of whites; not an Indian is to be seen. But on following dim trails radiating out from the settlement the homes of the Indians will be found. This lack of community life carries with it a corresponding lack of social organization, and, although there are chiefs, they are individuals who exercise only vague authority. The Indians, for the most part, are under the patronage of whites, whom they call “patrons”. Each white man exercises a sphere of influence over as many Indians as he can, and the rivalry between white men is rather keen, bitterness arising in case of conflict over the patronage of Indians. In return for the protection offered by the white the Indian will now and then do some work, especially in carrying supplies to and from Quito or in washing gold from stream gravels. The number of Indians is small, and it is difficult to induce them to work. The use of Indian labor to any large extent is, in the writers’ opinion, out of the question; construction of railways, pipe lines, highways, etc., will have to depend on white labor brought down from cities, such as Baños and Ambato, and in all probability on labor imported from the West Indies or some other region, as was done during the construction of the Guayaquil and Quito Railway.

The Jíbaros south of the Pastaza hold no allegiance to white masters and are in many ways superior to the Quechuas. They have strong, clean bodies and intelligent faces. They go armed with the deadly blowgun and long lances bearing iron heads. The men weave a good grade of cloth made from homespun cotton. They build strong houses of hard black palm, for each family is a unit and the house is a fort as well as a home. Sometimes twenty or thirty people live under one roof. They have gardens of yuca, plantain, papaya, and small red peppers. Polygamy is practiced. The name headhunter is applied to them from their practice of reducing the heads of enemies. These are used in ceremonial dances and for personal adornment. A great deal of the fighting between families is due to the witch doctors, who are called in to determine who has bewitched a sick person.

The Jíbaros who gathered at Alapicos to look over our outfit came from curiosity. They were not disposed to work, and we had nothing in the way of cloth or trinkets which would induce them to carry loads to Macas. They became interested when they learned that our guide had two small, stone jars of the black poison which they prize so highly for their blowgun darts. This poison is brought into the country by Indians from northern Perú where the secret formula is known. Our guide, Sr. Rivadeneyra, had obtained the poison from an Indian just as he arrived from Perú. The Jíbaros carried our equipment to Macas, a trip of eight days. Each Indian received about a teaspoonful of the black, sticky poison and felt well paid.

The white inhabitants are Spanish-speaking people who have migrated from the highlands of Ecuador. One of the striking features of these people is the fact that, though situated among Indians, they have preserved their purity of race. The total population of whites in the region from Archidona to Macas cannot exceed 600, and almost all of these are living in the town of Macas. This town is a unique settlement, located at an elevation of 3580 feet above the sea, distant eight days from the upland civilization by the most difficult travel on foot, in mud, and up mountainous cliffs. It is a town of perhaps 100 houses and nearly 500 people, cut off almost entirely from the civilization of the upland. Without commerce and communication, one wonders why this or any of the other such settlements continues to exist; yet their history dates back to the early settlement of South America by the Spaniards. Perhaps it can be explained by healthful conditions and the agricultural productivity of the region.

The great drawback of civilized development in eastern Ecuador is the lack of railways. The future depends on one thing, the continuation of the railway from Pelileo down the great natural gateway to the Oriente, the Pastaza River, and on the construction of branches north and south along the base of the Andes from a point like Mera. The Upano Trail and the Papallacta Trail are impossible routes of communication, being unfit for highway or railway construction.



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CHERTS AND IGNEOUS ROCKS
OF THE
SANTA ELENA PENINSULA OIL FIELD

by

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* Field work responsible

**Petrographic descriptions responsible

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INTRODUCTION

This paper describes the results of a visit to the Santa Elena Peninsula, Ecuador, in January and February, 1921. On account of the complicated folding and faulting of the rocks and the peculiar occurrence of petroleum, field work was possible on only a few of the many geological problems and the results here published are only a contribution to the solution of the general problem. We know of nothing published on the geology of the district, except one account, in Spanish and German, by Theodor Wolf ¹.

The Santa Elena peninsula, the most important headland of the coast of Ecuador, lies two degrees south of the equator. The chief town, Santa Elena, is about 75 miles west of Guayaquil, the main seaport of Ecuador. The nearest developed oil field is the Zorritos of northern Perú, 120 miles south across the Gulf of Guayaquil. If newspaper reports are true, *viz.* that the Anglo-Ecuadorian Oilfields, Ltd., has recently brought in a 700-bbl. well on the coast of the peninsula near Ancón, the district may become important in the production of petroleum. At the time of our visit, the best way to reach the peninsula was by a steamer of the Pacific Steam Navigation Co., southward from Panama and northward from Guayaquil. About once a week, one of these steamers anchored ½ mile off shore near the village of Salinas, an important cable station. An alternative route, in the dry season, is by automobile from Guayaquil. In February, 1921, a railway bed had been graded part way between Guayaquil and Salinas, but this was deteriorating rapidly because of lack of funds to continue construction or to keep in repair that portion already completed.

The part of the peninsula here described is an irregularly shaped area extending about 22 miles eastward, from the lighthouse to the mud volcano 5 miles east of the village of San Vicente, and from Punta Centinela on the north coast about 12 miles to a point on the south coast about 5 miles east of the fishing village of Ancón. The most striking feature is the finger-shaped point, averaging less than 1 mile in width and nearly 7 miles in length, which extends into the Pacific. In addition, there are three minor headlands, the Ancón and Punta Carnero on the south coast, and Punta Centinela, on the north coast.

The district is arid, treeless, fairly cool, and healthful; there is no cultivation of the soil except where it can be irrigated from wells. The population is small and limited to the vicinity of the wells. The chief industries are fishing, the making of Panama hats, the extraction of salt from the salt pans at Salinas (a Government monopoly), the collection of petroleum from the numerous pits, and the working of the cable station at Salinas, where a number of American and English employees reside. The largest town, Santa Elena, is the seat of the local government of the district and also possesses the only church in the region. Salinas has two hotels and a few summer homes. The population of neither Salinas nor Santa Elena exceeds a few hundred; the other hamlets consist of only a few Indian huts. There is telephonic and telegraphic communication between Salinas and Guayaquil. Automobiles can be rented at Salinas and one can drive all over the peninsula at any time of the year and as far east as Guayaquil, except in the rainy season, when the road is impassible near Guayaquil.

¹ Wolf Theodor (1892) Geografía y Geología del Ecuador.

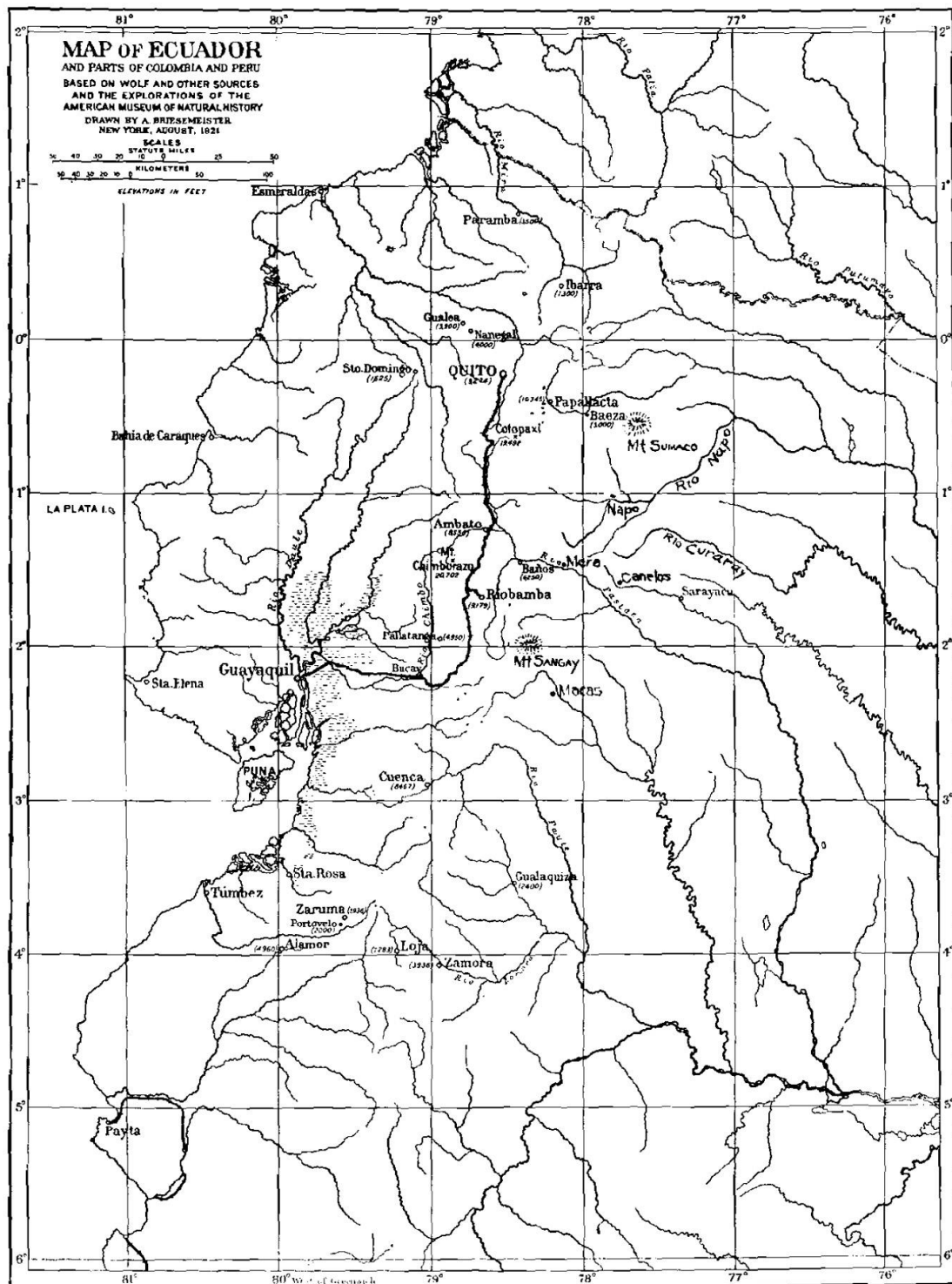


Fig. 1. – Map of Ecuador



Fig. 2. – Village of Ancón; cliffs nearly 200 ft. high. Semiarid conditions shown by cactus in foreground.

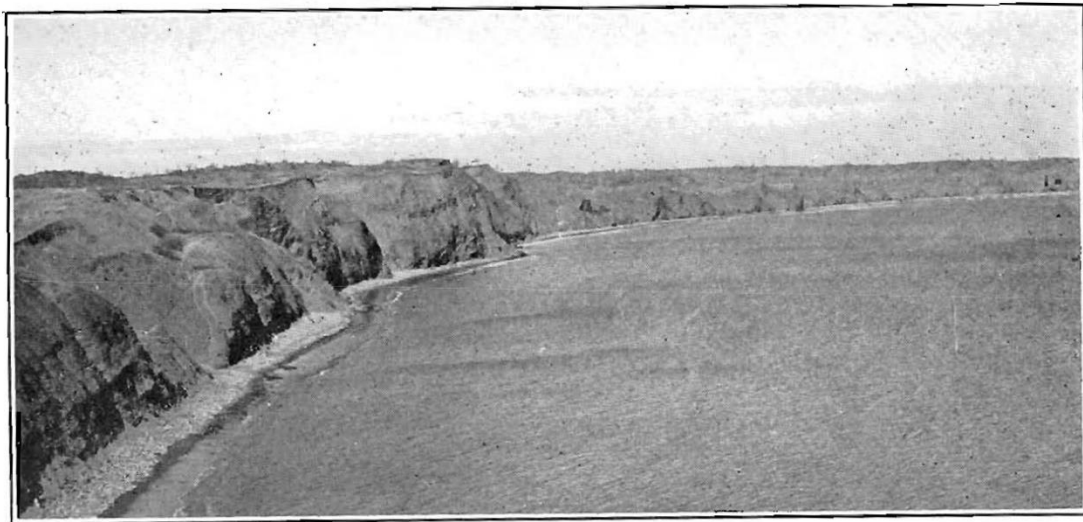


Fig. 3. – Cliffs in Tertiary sediments east of Ancón, on shore at extreme right are two wells of Anglo-Ecuadorian Oilfields, Ltd.

The western point of the peninsula is the dominating physiographic feature of the coast; it is an isolated, scarped, terraced, flat-topped hill, called La Puntilla, the summit² of which, 424 ft. above the sea, can be seen for many miles in every direction. Immediately southeast of this hill, the land lies almost at sea level, where Salinas and the cable station are situated. Eastward, the land rises gently, Santa Elena, 8½ miles from Salinas, being about 108 ft. above the sea and Volcancitos, 11 miles east of Santa Elena, about 250 ft.

² Chart No. 1123, Hydrographic Office, U. S. N., Washington, D. C.

The surface is thought to be a remnant of marine erosion recently elevated above the sea. From the presence of marine Pleistocene shells on the summit of La Puntilla, it would seem that there had been at least 424 ft. of recent uplift. The generally flat surface is modified by only one valley, Rio Grande de Salada, which is very shallow and contains water only for a short time after rain. This dry stream bed enters the area in the vicinity of Volcancitos and reaches the sea 1 mile west of Punta Carnero.

As would be expected in a region of such recent uplift, where movement is probably still continuing, there is considerable development of sea cliffs. These are especially well shown on the south coast between Punta Carnero and Chanduy.

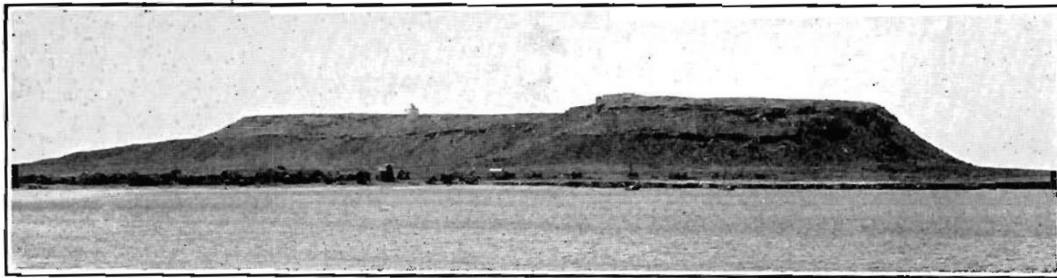


Fig. 4. – La Puntilla; elevation 424 ft.; elevation of light 467 ft. Notice terrace 30 ft. above the sea and remnants of others on slopes of the hill; in photograph terraces resemble strata. The hill is flat topped and composed of cretaceous cherts highly contorted and without signs of stratification; top contains shells, proving that it has recently been uplifted from the sea.

STRATIGRAPHY

The rocks of the peninsula may be divided into four groups: brecciated cherts, probably of Upper Cretaceous age; igneous rocks of limited extent intruding the cherts; a thick series of sandstones and shales of Tertiary age; and a thin formation of broken marine shells of Pleistocene age, probably the equivalent of the Tablazo of Perú.

The Chert Series

Neglecting a thin cover of Pleistocene beds, nearly one-half of the peninsula is made up of chert. La Puntilla is entirely chert. After a break about 1 mile wide, in the vicinity of Salinas, the cherts continue eastward over an unbroken area, 17 miles long and approximately 2 miles wide, extending to a point about 4 miles east of San Vicente. It is quite possible that they constitute the prominent ridge which runs eastward as far as Guayaquil, 85 miles distant, where similar rocks occur.

Nine specimens of the brecciated cherts were collected from widely separated parts of the peninsula and from these, thin sections were made. Photomicrographs are shown in Figs. 5 to 14.

Specimen E-C, Figs. 5 and 6, from the cliffs on the seashore below La Puntilla, is a reddish dense cherty limestone. Under the microscope it is microcrystalline, extremely veined, and is essentially a cherty infusorial limestone. The rock is not badly brecciated. Microscopic fossils are exceedingly abundant and well preserved and evidently made up almost the whole rock in its original condition. It was then probably essentially a carbonate, but has subsequently become opaline and cherty. This specimen preserves the original habit the best of any of the series

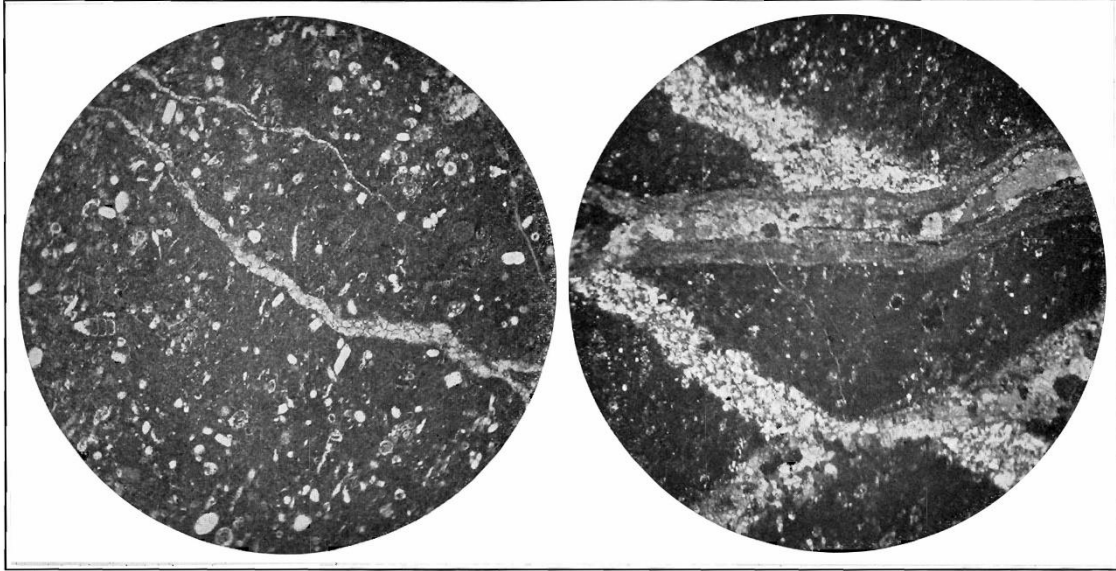


Fig. 5. — Specimen E-C; Infusorial cherty limestone; taken with plain light; $\times 30$. Structure similar to many of following specimens; especially in its exceedingly fine grain; abundance of microorganisms, and development of veinlets; composition largely carbonate but cherty where fossils are best developed and in some veinlets, but latest veinlets are carbonate.

Fig. 6. — Same slide as in Fig. 5 but taken with crossed nicols at different spot to show two types of veinlets formed in fractures. Carbonate veinlets cut all other structures and finer grained silica or cherty veinlets are cut by carbonate. It is similar to history shown in E-A. $\times 30$.

Specimen E-23, Fig. 7, from the extreme western point of the peninsula, is a fine dense, red, jaspery, infusorial chert, with many microscopic fossils, mostly infusorial. It is chiefly chert stained with iron oxide and carrying some carbonate. The minute fossils are plainly preserved, in spite of almost complete silicification. This particular specimen is less brecciated than others of the series but in all other respects it is similar to them.

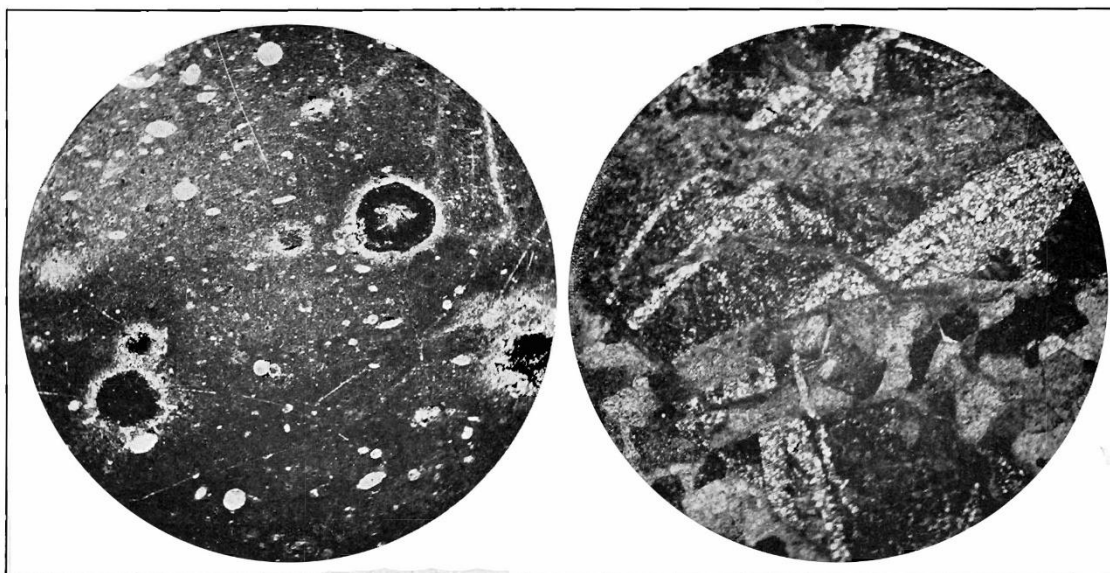


Fig. 7. – Specimen E-23; Jaspery infusorial chert; taken with plain light; $\times 30$. Shows very fine-grained jaspery character of rock with numerous microorganic forms scattered throughout.

Fig. 8. – Specimen E-A; Brecciated chert probably derived from infusorial rock; taken with crossed nicols to show double history of rock; larger uniform angular areas are brecciated cherty rock and represent original condition as nearly as is preserved; it is cut by veinlets of very fine aggregate cherty quartz, which stop abruptly at margins of present breccia fragments, which are bound together by carbonate. $\times 30$

Specimen E-A, Fig. 8, from cliffs at the extreme western point of the peninsula, is a dark-colored, highly brecciated, veined chert derived from an infusorial rock. It is like those already described, except that it is more broken. The earlier cementing material is siliceous, but the later healing material is carbonate. Brecciation, therefore, seems to have been going on during the change in conditions that have given it two different healing effects. This same habit has been noted in one or two of the other rocks, notably E-20.

Specimen E-20, Fig. 9, from La Puntilla, on the extreme western point of the peninsula, is a typical chert breccia cemented by carbonate. The rock, before brecciation, was a cherty type developed from a fine-grained organic deposit. From this specimen alone, it would be difficult to judge the nature of the original formation but other members of the series complete all gradations between this particular type of material and others in which microorganisms are prominent. In this specimen, the organisms are almost wholly obliterated by chertification and brecciation but otherwise it is like the other specimens. The rock probably was undergoing brecciation before chertification was completed. Thus, some of the fragments are complex, being themselves composed of breccia fragments cemented with chert. Later, carbonate became the healing material, rather than silica. All the later veinlets are carbonate.

Specimen E-B, also from the cliffs at the extreme western point of the peninsula, is a white, dense, weathered chert, of microfine texture. Its organic origin is much plainer than that of E-A and it shows a variety of fossils, chiefly foraminifera. The only difference between this sample and some of the more obscure cherty specimens is that the fossils are somewhat better preserved. The secondary structure is pseudomorphic and amorphous by replacement. Silica was the introduced substance and the rock may now be classified as an infusorial chert.

Specimen E-29, Fig. 10, from the isolated hill called “Carnero” on the south shore, is a white, exceedingly fine, close-textured, brecciated rock clearly of organic origin. The primary essential minerals were chiefly siliceous infusorial fragments. The rock is completely chertified but preserves multitudes of microorganic fragments of which it was originally composed.

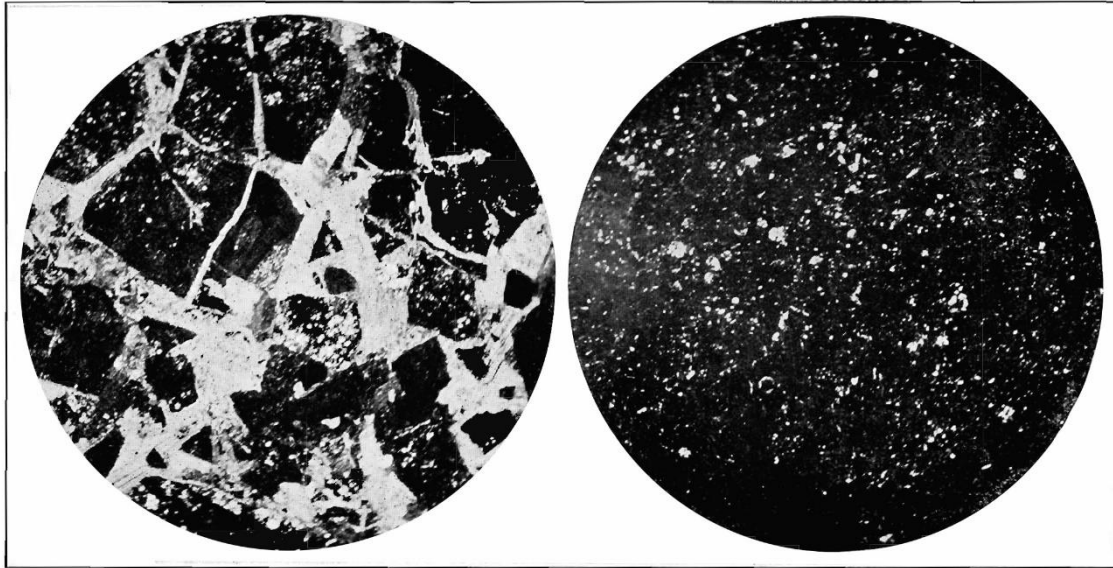


Fig. 9. – Specimen E-20; Brecciated cherty rock with abundant lime veining; taken with crossed nicols; $\times 30$. Shows brecciated character of rock; principal mass is fine cherty material, fracture filling and veinlets are carbonate; cherty portions show brecciation within themselves, as if broken while chertification was going on.

Fig. 10. – Specimen E-29; Cherty infusorial rock; taken with cross nicols; $\times 30$. Shows extremely fine grained rock; visible constituents are minute specks and flakes or rods, but scattered definite. Arrangements of them suggest a primary control, as in replacing an older structure; some are circular or ring-like indicating former presence of minute fossil forms.

Specimen E-44-D, Figs. 11 and 12, is from the second outcrop of cherts along the shore east of Salinas. Oil is obtained from neighboring pits in the same kind of rock. It is a dense, white, infusorial chert, of microfine texture; its original structure was organic. It is indurated, veined, and brecciated. The organic origin is proved by well-preserved fossils making a good connecting link between the specimens showing prominent fossil content and those fine cherty members in which the fossils have been destroyed.

Specimen E-22, Fig. 13, taken from an oil pit, is a greenish, brecciated, veined, fine-grained rock of microfine texture. Originally it was probably clastic, either ash or shale, now thoroughly silicified. The original minerals were quartz and probably a variety of other fine material, with pyrite. After deformation, carbonate, fluorite, and pyrite were introduced. This rock appears to have been more fragmental than most of the others but the only parts distinctly preserved are exceedingly fine-grained; the rest of the rock is cherty with veinlets of carbonate. It is thought that this was possibly an ashy shale that has been silicified in the same manner as the other rocks; but whether organic material was present in any considerable amount cannot be determined. The rock has many minute pyrite specks and is brecciated and extensively veined with carbonate. Some veinlets carry a colorless mineral, thought to be fluorite, which has not been noticed in other specimens.

Specimen E-40, Fig. 14, also, is from the oil pits and is a bluish or greenish-gray shaly, fine-textured, originally chiefly clastic rock with some organic remains. The primary minerals were quartz fragments, carbonates, mica plates, and fragments of fossils, especially foraminifera, glauconite and pyrite. This rock carries many mineral fragments, especially feldspar and quartz; the matrix is chiefly carbonate. It represents probably almost the extreme of clastic make-up of the series. Most of the other specimens are dominantly organic; the clastic material suggests the possibility of its derivation from an ash.

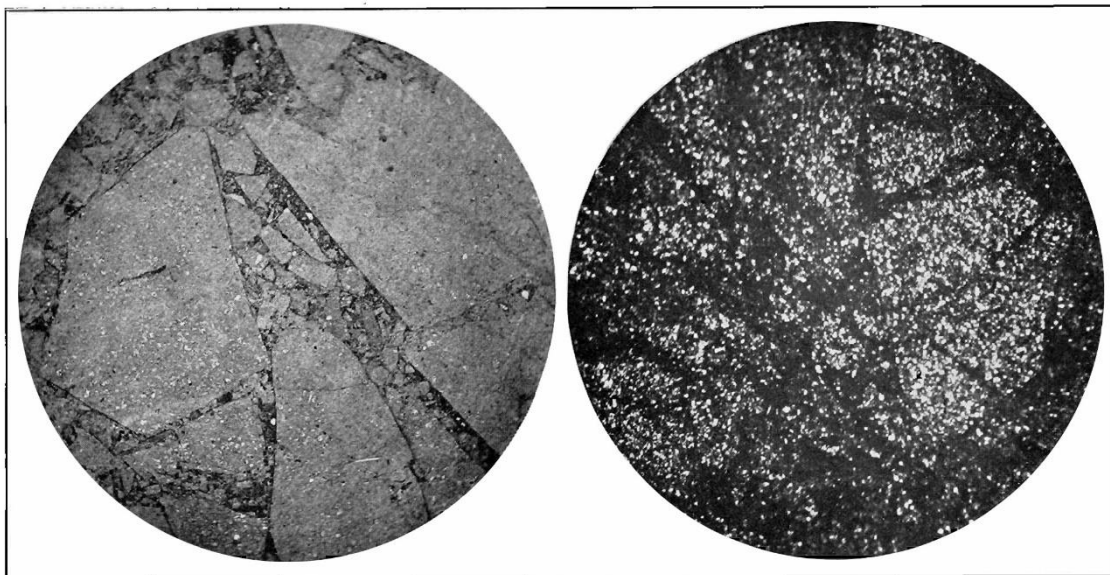


Fig. 11. – Specimen E-44-D; Brecciated rock essentially an infusorial chert; taken with plain light; $\times 30$. Shows fine uniform texture of rock and its brecciated structure. Smooth angular patches indicate brecciation since rock became solid; original structure, judged to have been organic, is largely obliterated by chertification processes.

Fig. 12. – Same field as shown in Fig. 11 but taken with crossed nicols to show extremely fine texture of rock; brecciated structure is not shown as well as in plain light; $\times 30$.

Some of the specimens shown are fine cherts in which original structures are almost wholly destroyed, whereas others well retain the original organic and clastic forms. There is no doubt that all had the same origin, being sediments composed essentially of siliceous and calcareous organic remains. In some specimens, there is much angular clastic material, which may be ash. The organic content varies widely. The tendency of the rocks is to chertify; nearly all are brecciated and veined with carbonate, which in some cases tends to replace part of the chert. Two or three are more obscure and carry finer fragmental material. The whole series represents beds of microscopic organisms, with some fragmental material largely silicified and greatly brecciated. In one case a little fluorite was noted in the veins; this is thought to indicate some igneous influence.

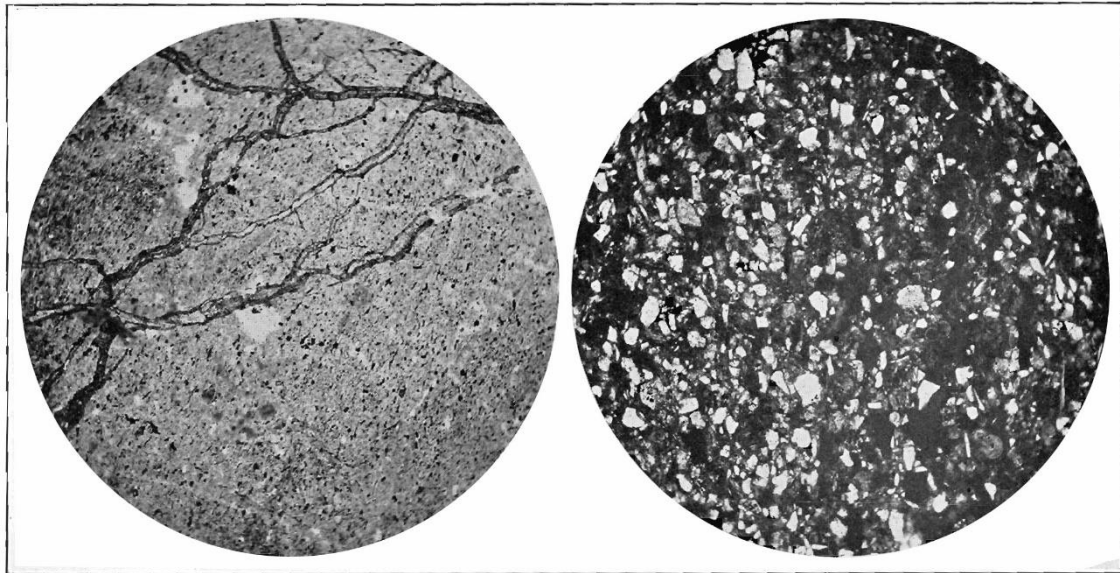


Fig. 13. – Specimen E-22; Silicified brecciated ash or shales; taken with plain light; $\times 30$. Shows fine-grain of rock and broken or veined structure; this is one of most obscure types.

Fig. 14. – Specimen E-40; Foraminiferal shaly grit probably carrying ash; taken with plain light; $\times 30$. Shows complex composition of rock including angular mineral fragments (clear), carbonate material (gray ground mass), minute fossil forms, less important constituents chiefly a small amount of limonite (very dark), and a little glauconite.

We have seen only microscopic fossils in these cherts. The series of slides examined by Dr. H. N. Coryell, of Columbia University, contains the following fossils: E-23, Spumellaria and Nassellaria; E-B, Spumellaria, sponge spicules, and Radiolarian spikes; E-C, Dentalina, Spumellaria, Rotalia, Orbulina universa and Textularia; E-40, Textularia cf. globifera, Orbulina universa, Globigerina and Rotalia; E-29, Spumellaria (very abundant), Radiolarian spikes, sponge spicules and Orbulina universa; E-44, Spumellaria, sponge spicules and Radiolarian spikes.

Doctor Coryell states: “The fauna consist of single to many-chambered, one-celled lime-secreting foraminifera and single-chambered silica-secreting radiolarians. Animals of this nature are pelagic, and move about near the surface of the sea in large numbers. The siliceous radiolarian remains are found in deep and shallow waters; the calcareous foraminifera and siliceous sponges are inhabitants of shallow seas.... The forms are consistent for Cretaceous age, some of them being equally appropriate for the Eocene. On the whole we judge that the series is Cretaceous.”

Structure of the Cherts

As the cherts are everywhere crushed there is no trace of stratification (see Fig. 15) and hence we have no idea of their thickness. The single place in the entire peninsula where some stratification is evident is immediately next to the diabase sills. Through the protective influence of this tough rock a few feet of stratification is preserved. Also the fact that the igneous rocks are not associated with the Tertiary sandstones and shales tends to prove that they were intruded before the Tertiary rocks were laid down.

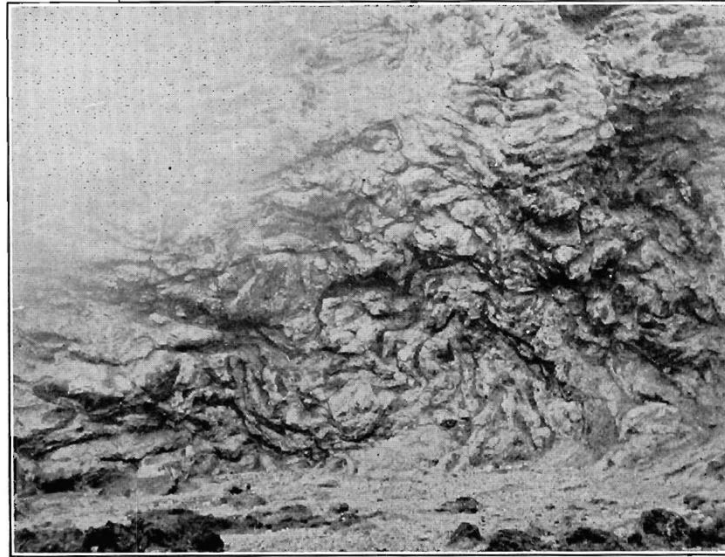


Fig. 15. – Cherts of Santa Elena Peninsula; note contorted attitude. (Photograph loaned by Theron Wasson).

Oils Pits in the Cherts

The pits from which petroleum is being obtained are in cherts. As shown in Fig. 16, there are six groups of petroleum pits, each group consisting of from 20 to 40 pits, varying in depth from 10 to 72 ft. and in diameter from 5 to 10 ft. These groups, beginning on the north coast, are: The Chilean Syndicate group, 1 mile west of Salinas; the Carolina Refinery group, 4 miles east of Salinas; the Republic Refinery group, a little over 3 miles west of Santa Elena; the Santa Paula group near the south shore, 5 miles southeast of Salinas; a group halfway between the Santa Paula and the Republic Refinery groups; two pits on the north shore northeast of the lighthouse.

In all these pits the oil oozes up through the cherts and collects at the bottom where it is gathered in buckets, lifted to the surface by windlasses, and placed in barrels which are rolled by burros to the refineries.

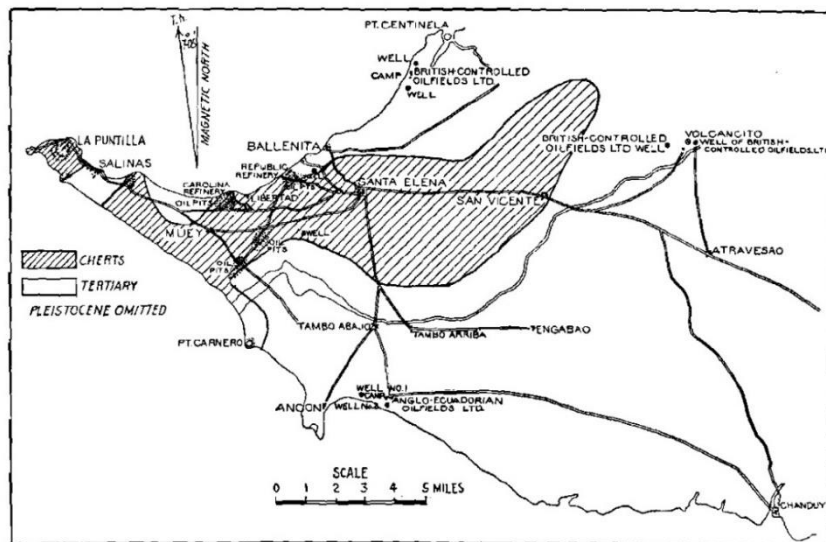


Fig. 16. – Santa Elena Peninsula

Igneous rocks

The areal distribution of the igneous rocks is negligible. They were found³ only on the north shore east of the Carolina refinery, and (as reported by Theron Wasson⁴) on the railway grade between Santa Elena and Volcancitos. At the Carolina refinery, five igneous dikes cut the cherts. In one place, they appear to be infolded with the cherts as though they had been first intruded as a sill into the cherts and later folded, faulted, and crushed with them.

Only one specimen (E-46) of this lot is described, Fig. 17; this was taken from the dikes or sills near Cautivo (Carolina refinery). It is a dark crystalline rock of medium texture whose original structure appears to be diabasic and somewhat porphyritic. The primary essential minerals are labradorite, augite, and some altered olivine. The primary accessory minerals are magnetite and apatite. The secondary minerals are chlorite, uralite and questionable serpentine, and some limonite. The rock is comparatively fresh, a fact which in the tropics does not mean that it is of recent origin. Only the olivine is altered. The rock has a diabasic structure and porphyritic habit, which is much more prominent than in the usual diabase. We have tried to indicate this double habit by calling it a porphyritic diabase. On account of its structural relation to the cherts we believe these igneous rocks also are of Cretaceous age



Fig. 17. – Specimen E-46; A porphyritic diabase; taken with crossed nicols; $\times 30$. Shows diabase crystalline structure of rock; one of larger phenocrysts of pyroxene extends into field from one side but field is made up mostly of well-formed lath-shaped plagioclase crystals, with pyroxene and altered olivine and magnetite occupying interstitial spaces.

³ A geologist who recently visited this region thinks that there are igneous flow rocks capping the upturned cherts and older igneous rocks and says that the reservoir for the village of Salinas is situated on this impervious lava capping. We have not seen this occurrence.

⁴ Theron Wasson, private report.

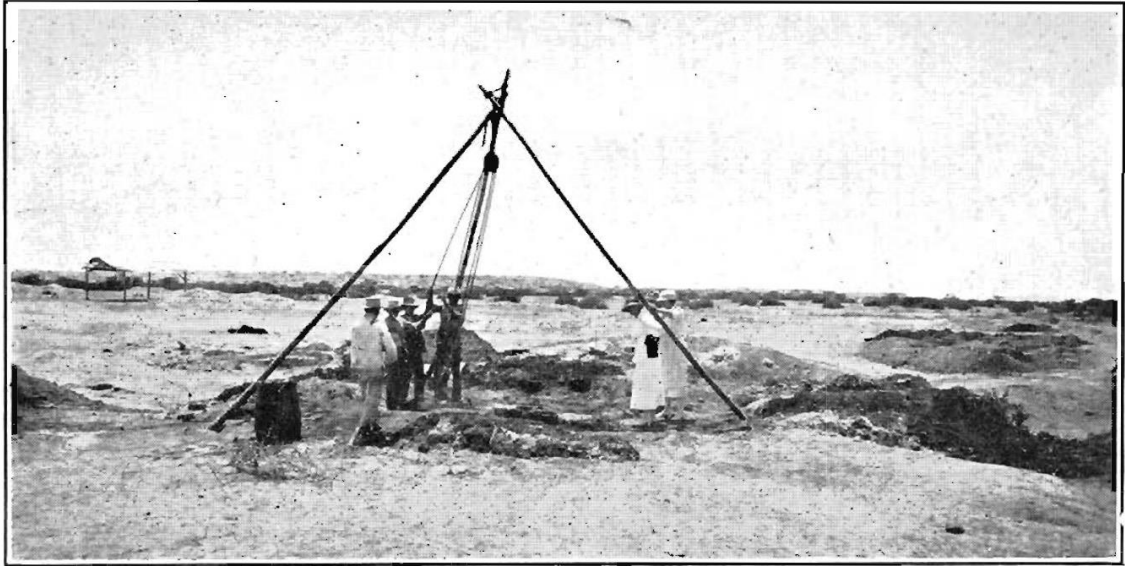


Fig. 18. – Tripod with pulley for lifting buckets of oil and water from pits, on the Santa Elena Peninsula.

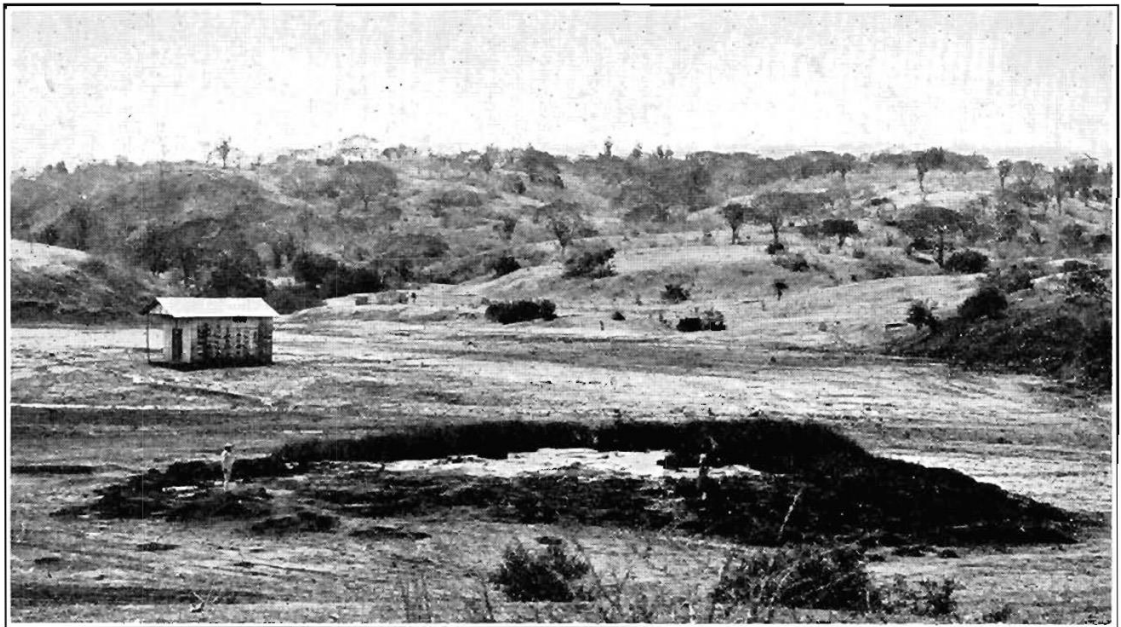


Fig. 19. – Mudvolcano near San Vicente; shed covers one of the hot medicinal springs where sick bathe.



Fig. 20. – Outcrop of Tertiary sandstones and valley near second well of British Controlled Oilfields, Ltd., Volcancitos.

Tertiary Sandstones and Shales

Disregarding again the areal extent of the Pleistocene, about one-half of the peninsula is made up of a thick series of sandstones and sandy shales with which no igneous rocks are associated and whose age we think is Tertiary, from the fact that they seem to overlie the Cretaceous cherts and certainly are older than the Pleistocene deposits. In the examination, we did not find any fossils except in the vicinity of Centinela, on the north coast, and unfortunately these were few and so badly broken that we did not attempt to study them. These sandstones and shales are probably several thousand feet thick and although on the south shore near Ancón they are discolored by a small seepage of petroleum, no beds of black carbonaceous shale occur in them. In a few places we noticed, especially near Centinela, on the north coast and near Ancón, small amounts of lignite and gypsum in the conglomerate which is found here and there. They are always highly contorted and faulted in the vicinity of the cherts but away from these the strata become less disturbed and, on the south shore, lie nearly flat although in them occur faults which appear to be of considerable throw, as on the Ancón headland. In general, the determination of anticlines is difficult. Two sharp folds occur on the north shore near Centinela and a broad fold is believed to exist in the vicinity of Ancón, where the Anglo-Ecuadorian Oil Co., Ltd., is drilling. In the upturned beds of the Tertiary rocks, 11 miles northeast of Santa Elena, is a mud volcano (see Fig. 19) 10 ft. high which has a cone about 100 ft. in diameter, while the top diameter is about 20 ft. It is built up of mud and tar. Gas constantly breaks through the central orifice, often with considerable force. Nearby are thermal springs which are considered medicinal.

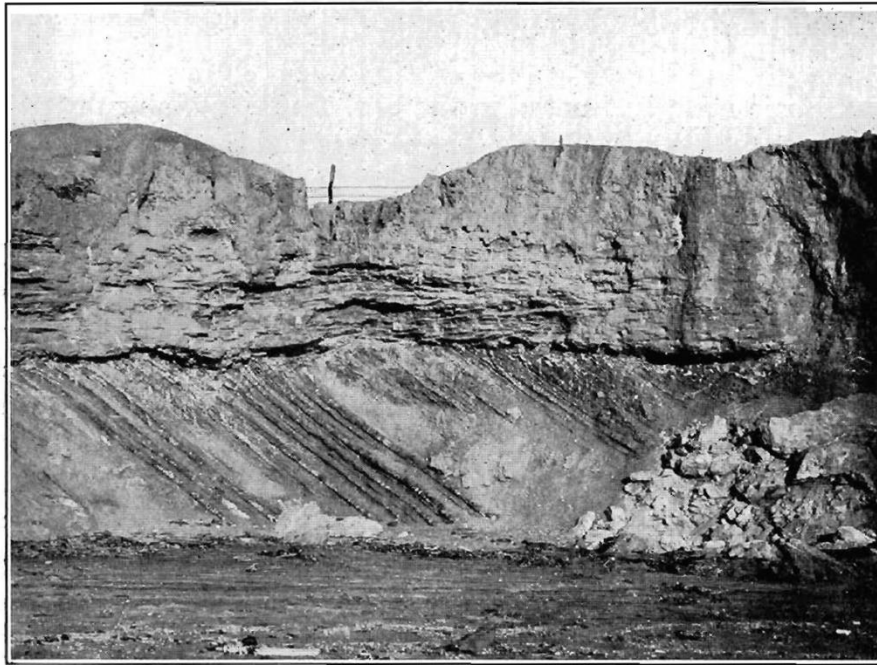


Fig. 21. – Pleistocene overlying in angular unconformity upturned Tertiary sediments of north shore of peninsula. (Photograph loaned by Theron Wasson).

Pleistocene Formation (Tablazo)

This formation occurs as a thin covering over the Cretaceous and Tertiary rocks and is somewhat widespread, see Fig. 21. It is made up of marine shells and contains, in places, bones of vertebrates. Of the four classes of rocks found on the peninsula, this is generally regarded as of the most certain age. We have, however, seen no list of fossils from it. Wolf⁵ in describing the vertebrates of this formation, says that in the vicinity of Santa Elena are found large bones that have been determined to be of *Mastodon Andium* and *Equus Andium*, the same as are found on top of the Andes in the tuffs and alluvial beds near Riobamba, Ecuador⁶.

⁵ Wolf Theodor (1892) Geografía y Geología del Ecuador.

⁶ Branco W. (1883) Über eine fossile Säugethier Fauna von Punín bei Riobamba in Ecuador nach den Sammlungen von W. Reiss und A. Stübel. Geol. Und Palaeont. Abhandlungen, 1, 2, 166 pages.

*[The American Institute of Mining, Metallurgical and Petroleum Engineers,
January 1924, pp. 195-207]*

**OIL DEVELOPMENT
IN ECUADOR
DURING 1923**

by

JOSEPH H. SINCLAIR

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INTRODUCTION

The Republic of Ecuador is situated partly in the northern and partly in the southern hemisphere. The equatorial line passes about 11 miles north of Quito, and divides the country into two almost equal parts.

Crossing the equator almost at right angles, and extending from Colombia into Peru, the Andes form a great upland that, in cross-section, resembles a truncated cone, the top of which is about 40 miles wide and about 10000 ft. above the sea, while the base is about 80 miles wide extending from sea level, on the Pacific Coast, to the Amazon Plain, on the east. Superimposed on this upland are many active and extinct volcanoes, which form roughly two parallel chains of mountains, on the eastern and western boundaries, respectively, of the plateau. These are often referred to as the Eastern and Western Cordilleras of the Andes, although their parallelism is somewhat questionable. The highest of these mountain masses is Chimborazo, about 21000 ft., above the sea; among the others is the volcanic peak, Cotopaxi, rising to about 18000 ft. above the sea.

The development of the petroleum resources of Ecuador is greatly affected by this Andean mass, not only because of its composition and geological structure but because of the barrier it interposes between the lowlands on the Pacific side and whatever part of the Amazon Plain to the east is finally found to belong to Ecuador, for the eastern boundary of the Republic is still in dispute with Peru. To understand, therefore, the development of the petroleum resources of the Ecuador and the barriers to such development, we must bear in mind the three great physiographic divisions, viz.: the Pacific Coastal region on the west, the Andean Plateau in the center, and the Amazon Plain on the east.

The first important effect of the threefold physiographic division is that Ecuador has two sets of petroleum regulations: one for that portion east of the Andes, and one for the Andean Plateau and the Pacific Coastal region although it is probable that the two sets of regulations are, in part, due to the boundary dispute with Peru.

The development of the petroleum resources of Eastern Ecuador, or the "Oriente", is regulated by the decree of Nov. 26, 1920, which gives to the President the power:

"First, to make adjudications under the terms and conditions which may seem prudent or convenient of petroleum deposits in the Region Oriental; and second, the authority to exploit said deposits directly or through the agency of national or foreign companies with which ad referendum contracts, that may be deemed convenient, may be entered into."

This decree places almost unlimited power in the hands of the President.

The development of petroleum in all that portion of Ecuador, other than the Region Oriental, is regulated by the law of Oct. 18, 1921, with an amendment on Oct. 20, 1922, which allows the president the right to concede the exploitation to any one person or company, of blocks of 5000 hectares (12355 acres. or about 19 sq. mi.) for a period of 40 years with the right to an extension of 10 years, the royalties varying between 5 and 12 per cent.

Petroliferous rocks of Cretaceous and Tertiary age originally covered all of Ecuador but the uplift of the Andes Mountains, in late Tertiary time, has done away with all but remnants of the Tertiary in the Andean region. This has broken and faulted and covered with masses of volcanic debris the Cretaceous of the Andes and has modified considerably the attitude of the Tertiary and Cretaceous to the east and west of the mountains.

DEVELOPMENT OF PETROLEUM IN THE PACIFIC COASTAL REGION

The geology of this region was practically unknown until recently when, with increasing attention to petroleum, the geology of that part along the Gulf of Guayaquil and the Pacific Ocean has been studied.

Although often referred to as the Pacific Coastal Plain, the greater portion of the region is hilly with ranges of mountains attaining an altitude of 2500 ft. above the sea. Along the coasts, however, there are narrow parts of true coastal plains; to these, the development of petroleum has so far been restricted. The surface of the Pacific Coastal region is mainly made up of Tertiary and Pleistocene sediments through which here and there, like islands, rise mountainous areas, in part at least, of Cretaceous rocks.

Drilling for petroleum has been carried on in three parts of this; *viz.*, in the vicinity of Manta on the Pacific Coast, 120 miles in an air line northwest of Guayaquil; in the Amen district, 30 miles southwest of Guayaquil; and in the vicinity of the Santa Elena Peninsula, about 57 miles west of Guayaquil.

Developments near Manta

The surface in the vicinity of Manta consists of Pleistocene terraces standing about 50 ft. above the sea, in which we know of no seepages of gas or petroleum. Drilling has been in the nature of wildcatting with the hope that the petroliferous formations of Santa Elena could be encountered at reasonable depth. The only company to drill has been the International Petroleum Co., Ltd., of Canada which began late in 1920. Two wells have been drilled. The first called Manta No. 1, was situated directly on the seacoast 6 miles north of Manta and about 1½ miles west of the village of Jaramillo. This well was abandoned in June, 1922, after reaching a depth of 3425 ft., having found only small showings of gas and many water-bearing sands. The second well, Manta No. 2, was located in the Pacoche River valley, about 10 miles southwest of Manta and 3 miles from the coast. This well reached a depth of 1350 ft. and was abandoned in July, 1923. From 850 ft. down, it penetrated hard black shale and dense basaltic rocks. No favorable indications of either oil or gas were found in this well and we understand no further development is being planned.

Developments near Amen

Interest in this region, situated about 20 miles north of the Gulf of Guayaquil and about 30 miles southwest of the city of Guayaquil began, in 1921, with the discovery, by geologists, of an anticlinal structure where it was thought the petroliferous formations of Santa Elena might be encountered at reasonable depth. The axis of this fold is first noticeable 4 miles north of Billingota and bears east through the vicinity of Meami. It is last noted about 2 miles south of Bajada. This stretch of about 17 miles has been entirely covered by petroleum claims. The flanks of the fold have dips of from 10° to 15°; the surface is in Miocene beds.

Following the lead of the Standard Oil Co. of California which at present controls an area aggregating about 150 sq. mi., the South American Gulf Oil Co. and the International Petroleum Co., Ltd., of Canada have obtained holdings, the former controlling about 140 sq. mi. and the latter about 110 sq. mi.

The Standard Oil Co. is the only company, so far, to begin drilling. A well was started on the crest of the fold about 8 miles northeast of Amen and at the present time is at a depth of 3600 ft. This is being drilled with cable tools and has not found any oil. It is reported that a showing of gas was met with at a depth of 2850 ft. In addition to this drilling the Standard has improved the highway between Guayaquil and Chongón, constructed a new road between Chongón and the well site, and improved the road between the well site and Billingota. The camp, which is about, 8 miles northeast of Amen, is of modern equipment. It is, in reality, a small town for the accommodation of about 110 Ecuadorian, 6 European, and 13 American employees.

Developments on Santa Elena Peninsula

The Santa Elena Peninsula¹ forms the most westerly land of Ecuador and is situated about 75 miles west of Guayaquil. So far, this region has produced all the oil of Ecuador; also, until recently, nearly all the production has been obtained from surface pits excavated by hand. Since the war, drilling by modern methods has been carried on with some success and, at present, most of the peninsula is in the control of the Anglo-Ecuadorian Oilfields, Ltd., of London, the Mackay-Harmsworth Oil Exploration Co., Ltd., the International Petroleum Co., Ltd., of Canada, and the South American Gulf Oil Co. The Standard Oil Co. of California has several tracts between Volcancitos and the south coast.

The existence of petroleum on the Santa Elena Peninsula has been known apparently for more than two centuries. Redwood² states that Velasco's "History of the Kingdom of Quito", published in 1700, contains an account of the operations carried on for the production of pitch at Santa Elena. Theodor Wolf³, who visited the region in 1873, describes the pits for collecting the petroleum, which he stated exudes in drops, together with salt water, from the sides of the pits. Then, as now, the oil was skimmed from the salt water.

At present, there are about 2000 pits on the peninsula, placed in several groups. The most westerly group consists of about 50 pits near, the village of San Lorenzo, on the north shore about 2 miles east of Salinas. This is the property of the Empresa Luz y Fuerza Eléctrica of Guayaquil. The production from these pits is reported to be about 300 bbl. per month and is obtained from Pleistocene sandstones, in part overlying crushed cherts and in part overlying slickensided shales of Upper Cretaceous age. The crude oil is shipped, in small boats, to Guayaquil for use as fuel in the electric-light plant and for use in enriching the product of the city gas plant.

Another group of pits is on the north shore about 5 miles east of Salinas. This is the property of Senor Lecaro, who has a small refinery on the shore north of the pits. He also controls another group of pits on the Santa Elena claim, about 2½ miles south of the refinery. In these two groups, there are about 600 pits ranging in depth from 10 to 50 ft.

¹ Sinclair Joseph H. and Berkeley Charles P. (1923) Cherts and Igneous Rocks of the Santa Elena Oil Field, Ecuador. *Trans.*, 69, 79.

² Sir Boverton Redwood (1896) A Treatise on Petroleum. 1, 103.

³ Wolf Theodor (1874) Relación de un Viaje Geognóstico por la Provincia del Guayas, Quito.

Two other groups of pits, about 600 in number, are controlled by the Mackay-Harmsworth Oil Exploration Co., Ltd. One group is found on the north shore about 2 miles northwest of the village of Santa Elena; on the shore nearby is the Cautivo or Republic refinery of this company. The second group is situated on the claim called "Achallan", about 1 mile northeast of the Santa Paula group.

There are several hundred pits near the foregoing groups, which are controlled by scattering interests.

The oil from all these pits comes from crushed cherts with which igneous rocks are associated. The cherts, in places, are covered by a thin covering of Pleistocene shore material. The igneous rocks appear to have been originally sills of a diabasic character in the predecessors of the cherts, and were later involved with them in the subsequent folding and crushing that has entirely destroyed the sedimentation of the cherts. Some of the oil has impregnated the overlying horizontal Pleistocene deposits.

The oil from the pits varies from 24° Bé. to almost pure asphalt. None of the pit oil is refined but is used for fuel oil and for the extraction of pitch. The greater part of the pit oil is shipped to Guayaquil for use as fuel.

The first figures on production of the pits are for 1909, when Clerc⁴ gives the production at 300 tons (about 2100 bbl. monthly). In another place, Brodie gives the production of 20 pits at from 600 to 800 bbl. per month, stating that some of the pits produce as much as 7 bbl. a day at first. Mercer⁵ gives the production, for 1913, at 10000 to 20000 bbl. In 1921, the production was estimated to be 4000 bbl. monthly.

Drilling for petroleum, as contrasted with digging, naturally began in the cherts near the pits and has since been extended to the Tertiary formations to the east.

At present, the following companies have done drilling: Senor Lecaro, the Mackay-Harmsworth Oil Exploration Co., the Anglo-Ecuadorian Oilfields, Ltd., and the British Controlled Oilfields, Ltd.

Senor Lecaro has about six wells of 300 ft. average depth all in the cherts or their thin covering of Pleistocene deposits. Three of these wells are near the refinery, 5 miles east of Salinas, and three in the vicinity of Santa Paula. Some of these wells are reported to have produced about 14 bbl. a day at first. Their average production is now about 4 bbl., daily, each. This oil is of much lighter gravity than the pit oil, as is all the deep oil on the peninsula, averaging from 35° to 37° Bé. and containing from 30 to 35 per cent. gasoline and 28 per cent. kerosene. The Lecaro refinery, at Carolina, we understand treats only the oil from these shallow wells. This refinery, also known as the Viggiani refinery, is the oldest on the peninsula and now produces, according to report (probably exaggerated), more than 3000 cans a month each containing 5 gal. of gasoline. The refinery is of the simplest type — a skimming plant consisting of a single horizontal still of about 500 bbl. charging capacity. A 2 in. pipeline about 2 miles long carries the light oil from Santa Paula to the Carolina refinery.

⁴ Brodie Walter M. (1919) Petroleum in Ecuador. *Eng. & Min. Jnl.* 107, 941-944.

⁵ Mercer J. W. (1916) Mining in Ecuador. *Eng. & Min. Jnl.* 101, 343.

The Mackay-Harmsworth Oil Exploration Co. has five or six shallow wells, probably about 300 ft. deep on their Achallan claim 1 mile east of Santa Paula. These wells are also in the cherts and produce a light oil similar to the Santa Paula oil, which is conducted in a 2 in. pipeline about 2 miles to the Mackay-Harmsworth refinery on the north shore, about 2 miles northwest of Santa Elena.

This company also has four wells, less than 500 ft. deep, on the terrace just west of Santa Elena and a fifth, about 2250 ft. deep, in the same vicinity. The shallow wells each produce about 3 bbl. per day.

The Mackay-Harmsworth Co. is now drilling a well on the Aquiquimi claim, southwest of Cautivo, and is now about 1800 ft. deep. It has obtained a number of oil and gas showings. The light oils from the wells are refined in its refinery at Cautivo, which is of about the same type as the Lecaro refinery at Carolina. The oil, like the other light oils of the peninsula, varies from 35° to 37° Bé. and contains from 30 to 35 per cent. gasoline and 28 per cent. kerosene.

The Anglo-Ecuadorian Oilfields, Ltd., of London, entered this field in 1918 when Lobitos Oilfields, Ltd., took over 150 sq. mi. of territory on the peninsula and north as far as Ayangue. It announced that its geologists, after examination, had formed a favorable opinion of the possibilities. At the time of the purchase, one well was drilling near Ancon on the south shore. This was a radical departure from previous drilling, which was limited to the cherts in the proximity of the oil-bearing pits, but the drilling was justified because of signs of oil in the Tertiary sandstones on the seashore east of Ancon and because of a flat anticlinal in the Tertiary beds.

The Lobitos Oilfields announced that this well, at a depth of 2000ft. when the ground was purchased, was producing in modest quantity. In 1919, the property was transferred to Anglo-Ecuadorian Oilfields, Ltd., formed to take it over. In April, 1921, this company announced that this well, described in its announcement of July, 1918, had reached oil at more than 2500 ft. and that owing to the small bore deeper drilling was not carried on. The production of this well, hereafter known as No. 1, was given at 5 bbl. per day. In December, 1921, the company announced that the well continued to flow periodically and reports at the end of 1923 state that the production is about 3 bbl. per day.

The second well drilled by this company, No. 2, is situated, like No. 1, on the seashore east of Ancón. It was reported by the company that, in March, 1921, oil was struck at 2562 ft. In December, 1921, it was announced that this well had been deepened to 2807 ft. when it began to flow and as the gas pressure was considerable, it was resolved to finish off the well. Announcements have been made that this well had since flowed at intervals in such volume as to indicate that if it were pumped, production would be fully up to that of an average Lobitos, Perú, well. The latest information is that in June, 1923, the production was about 37 bbl. per day.

In December, 1921, this company announced that a third well, No. 3, had been started and was at a depth of 196 ft. While it was reported a year later that this well was in difficulties and was located on a fault, a recent report shows that eventually it had been drilled to a depth of 3350 ft. and abandoned without having found any oil. This well is the first of a series drilled on the high land away from the coast. The 150 sq. mi. controlled by the Anglo-Ecuadorian Oilfields, Ltd., extends north as far as Ayangue 44 miles north of Santa Elena. In December, 1921, it was announced that a well was being drilled at Ayangue on the coast and that the latest depth was 2290 ft. Nothing further has been heard of this well. We understand it was abandoned at the depth noted.

The fourth well drilled by this company, No. 4, had in December, 1922, reached 2000 ft. Latest reports are that this well was in an oil sand at a depth of 3030 ft. and pumping 50 bbl. daily.

No. 5 well, like numbers 1, 2, 3, and 4, was located in the vicinity of Ancon and, in December, 1922, was at 790 ft. A year later, it was said that this well had started in as a gusher and had ejected large quantities of oil to a height of 150 ft. and, before being capped, commenced to produce at the rate of 500 bbl. per day. Dr. F. W. Goding⁶ the American Consul General at Guayaquil, reported that this well was producing 250 bbl. per day. Latest reports are that this well found oil at 2000 ft., where it commenced with a production of 200 bbl. daily, which diminished in three months to 100 bbl. daily, and that now the production is 75 bbl.

No. 6 well was first reported, in December, 1923, as drilling at 3100 ft. and showing strong gas pressure. On Jan. 1, we are informed, this well had reached a depth of 3160 ft. without having found traces of oil.

No. 7 well began drilling in April, 1923, and was reported, on Jan. 1, 1924, to be at 1600 ft., having found traces of petroleum.

An eighth well is now drilling and the derrick for No. 9 is being erected.

Summing up the production, we have the following:

No. 1 well at 3 bbl. per day gives for one month.....	90 bbl.
No. 2 well at 37 bbl. per day gives for one month.....	1110 bbl.
No. 4 well at 50 bbl. per day gives for one month.....	1500 bbl.
No. 5 well at 75 bbl. per day gives for one month.....	2250 bbl.
Total monthly production.....	4950 bbl.

Lord Torres, at the last annual meeting of the Anglo-Ecuadorian, on Dec. 3, 1923, stated that the results of the drilling had been satisfactory, that the present production was 3600 bbl. per month, and that although wells in Ecuador, as in Peru, are not likely to be large producers, the quantity of the oil was more than their limited tankage could cope with, therefore the wells had been held down. He said they had now proved the existence of oil in paying quantities in an area sufficiently large to justify the construction of a railway, pipeline, a new port, tanks, etc.

⁶ Dr. F. W. Goding (1923) Petroleum Development in Ecuador. Commerce Reports, (July 23, 1923), 224.

In addition to the two different figures on production just given. Doctor Goding⁷ says that the monthly production about June, 1923 amounted to 8000 bbl. per month, while a very recent report by the agent of the Anglo-Ecuadorian at Guayaquil to the Government states that the production amounts to 1800 bbl. per month. The average of these various estimates is 4587 bbl. per month, which, on the basis of 30 per cent. gasoline content, would give a monthly gasoline production of 57796 gal. If reports are true that the refinery has been shipping 15000 gal. monthly to Guayaquil since its completion, the production of crude is probably exaggerated in all estimates above 1800 bbl. a month for the Anglo-Ecuadorian. Checking the crude production by the gasoline production, it would seem that the 1800 bbl. per month, as given on Jan. 1, 1924, by the agent of the company is more nearly correct than the other three, as this gives a gasoline production of 22680 gal. monthly on the basis of the crude having a 30 per cent. gasoline content. We could understand thus the shipment of 15000 gal. monthly and a local use and sale of the balance, 7680 gal.

The only analysis we have of the quality of the oil is that given by Doctor Goding of 12 bbl. from No. 5 well, which analyzed as follows:

	GALLONS	PER CENT
Gasoline	150	29.77
Commercial benzine	112	22.22
Kerosene	72	14.28
Residue	170	33.73
Total	504	100.00

The Anglo-Ecuadorian has a refinery at Ancon and it is reported 15000 gal. of gasoline have been shipped monthly to Guayaquil since its completion. At the refinery, there are three tanks, one of 20000 gal. capacity for gasoline, one of 30000 gal. for kerosene, and one of 20000 gal. for benzine.

A new port has been constructed at La Libertad, on the north shore of the peninsula, about 10 miles north of Ancon. Here, a pier 360 ft. long and 13 ft. wide has been constructed. The water alongside is about 25 ft., deep, and it is expected to deepen this to 30 ft. so that oceangoing steamships can bring material direct to the peninsula without trans-shipment at Guayaquil.

At La Libertad, two storage tanks have been completed, each about 90 ft. in diameter and 30 ft. high with a reported capacity of 35000 to 50000 gal. each. It is understood that three more are to be constructed in the near future.

Between Ancon and La Libertad, there has been constructed a railway and a 6 in. pipe line and two pumps of 200 gal. capacity per minute under pressure of 250 lb. per sq. in. are being installed at Ancon.

The camp at Ancon is of modern equipment with electricity, ice plant, and plant for obtaining fresh water from sea water, etc.

⁷ Loc. Cit.

The British Controlled Oilfields, Ltd., entered this field late in 1920, and after drilling four wells withdrew from the peninsula; litigation appears to be largely responsible for their withdrawal. The first well was located in the Tertiary beds at Volcancitos, 11 miles northeast of the village of Santa Elena. Here is found a mud volcano, the truncated cone of which, built up of tar and mud, is 10 ft. high, 100 ft. in diameter at the base and about 20 ft. diameter on top. Gas breaks constantly through the central orifice, often with considerable force, causing a booming that can be heard several miles. Nearby are thermal springs with the evolution of considerable gas; these are considered curative for certain diseases. The location for the well was about 300 ft. from the mud volcano and near the springs. After reaching a depth of about 400 ft., drilling was abandoned because of hot salt water and mud. A second well was begun in the same valley about 1 mile southwest; this was a failure from the same causes. Reports vary in stating the depth reached as between 150 and 800 ft. Mr. White, the driller, told us that in excavating for the derrick of the second well, they found bones of vertebrates in the thin covering of Pleistocene deposits overlying the Tertiary. Theodor Wolf states that bones of Mastodon Andium and a prehistoric horse, Equus Andium, are common in the Pleistocene of the Santa Elena peninsula.

The British Controlled then began drilling two wells on the north shore of the peninsula, about 4 miles northeast of Santa Elena, near Point Centinela. The most northerly of these wells was drilled to about 1800 ft. and abandoned. The other well, 1 mile south was abandoned also at a depth of about 1000 ft. These two wells were drilled in Tertiary sediments on a narrow anticlinal fold; it is unfortunate they were not drilled to greater depths for they cannot be considered a fair test of the property.

According to Goding, the crude production in 1922 amounted to 50000 bbl. The monthly production of crude for a portion of the early part of 1923 was:

PRODUCTION IN BARRELS	HEAVY OIL	LIGHT OIL	TOTAL
Anglo-Ecuadorian Oilfields, Ltd		8000	8000
Mackay-Harmsworth Oil Exploration Co. Ltd	1900	2800	4700
Lecaro properties	700	600	1300
Juan Alberto Pachano	300		300
Maulme and others	650		650
Metropole	200		200
Total	3750	11400	15150

These figures appear to be too high because of the great discrepancy between the output of light oil and the percentages of gasoline computed on the basis of 30 per cent. gasoline content. We have shown that the Anglo-Ecuadorian is probably producing, at the most, 1800 bbl. per month instead of 8000 here given. The production of the Mackay-Harmsworth wells, on the basis of 3 bbl. per day for the shallow wells and 10 bbl. for the deep well would amount to 1200 bbl. of light oil per month instead of 2800. Assuming a production of 3 bbl. per day for Senor Lecaro's shallow wells, his light-oil production would amount to about 540 bbl. per month. The total light oil production would appear to be:

	BARRELS
Anglo-Ecuadorian Oilfields, Ltd.	1800
Mackay-Harmsworth Oil Exploration Co.	1200
Lecaro	540
Total per month	3540

With even this reduced figure for light oil, *i.e.*, from 11400 bbl. monthly to 3540 bbl. we cannot account for a lot of missing gasoline. On a 30 per cent. gasoline content 3540 bbl. would give about 44000 gal. per month. Figures given by Doctor Goding, for February, 1923, are 7720 gal. of gasoline and 7470 gal. of kerosene; and for July 12440 gal. of gasoline and 7320 gal. of kerosene. His figures for the first half of 1923 are: gasoline, 41230 gal. and kerosene, 29320 gal. It may be that a large amount of crude light oil is being sold elsewhere than to the refineries.

Accepting our figure of 3540 bbl. per month of light oil and Doctor Goding's of 3750 bbl. for heavy oil gives a total monthly production of 7290 bbl., or 87480 bbl. a year.

THE ANDEAN UPLAND

Although the Cretaceous, and probably lower Tertiary, have been involved in the Andean uplift, for the most part these are concealed by the volcanic debris of the various volcanoes scattered along the crest of the Andes. Petroleum claims, however, have been taken up in two districts where the sediments are exposed; *viz.*, in the vicinity of Calacalí and Nanegal a few miles north of Quito, and in the Cuenca Basin, a few miles north of the Peruvian boundary. There has been no development in either district.

North of Quito, there are traces of petroleum and small seepages of gas in the bottoms of certain valleys where erosion has exposed small amounts of the sedimentary rocks under the masses of tuff that cover the country. Nothing is known of the age of the stratified rocks exposed. The igneous rocks, in one or two places, also are impregnated with a slight amount of petroleum. In a short visit to this locality, in 1920, we did not attempt to work out the structure of the sedimentary rocks, which are greatly fractured and faulted.

In the Interandine Cuenca Basin: rocks of Cretaceous age occur, particularly the Azogues sandstone. This formation is always broken and strongly tilted, generally from 45° to 80° to the west with a strike of north-south. Little is known of this region except that bituminous substances impregnate in certain places the Azogues formation and that asphalt is common. The bituminous beds, in some places, are several meters thick, but the pure asphalt occurs in very thin strata.

THE AMAZON PLAIN

About May, 1921, the President of Ecuador, acting under authority granted him by the Legislative Decree of Nov. 26, 1920, granted to the Leonard Exploration Co., of New York, a concession for the development of the petroleum resources of a large area in eastern Ecuador. The two parcels of this area gave to this company prior rights on an area of about 9000 sq. mi. The application for this concession had been based on information obtained from Indians that lead to the belief in the existence of petroleum in this region.

On Aug. 1, 1921, Theron Wasson and the author entered the Amazon jungle by way of the Pastaza Valley seeking information as to the geological conditions at the base of the Andes. They emerged, Dec. 1, in the Upano Valley, a few miles above Macas. A preliminary description⁸ has been published but the geological results have not been given out. Large collections of fossils were made and the existence of Upper Cretaceous formations highly impregnated with bituminous material, asphalt, etc. was proved. Seepages of inflammable gas were found and a striking fact noted, *viz.*, the presence of these Upper Cretaceous formations under good conditions of folding, gentle dips, etc., which make it probable that in this region petroleum will be found in considerable quantity. Unfortunately, the terms of the original concession were very severe; and while modifications have been made it has not been possible for the Leonard Exploration Co. to finance operations. At present, American companies feel that the problems in bringing out oil across the Andes or down the Amazon are too great for solution.

A proposition was made, in 1922, to the Ecuadorian Government by a large American oil company to develop a portion of the region; but although the contract acceptable to this company would have been eminently fair to the people of Ecuador, it was not accepted by the President. An effort was made, in 1922, to form a syndicate of a number of American oil companies and obtain control of the entire region east of the Andes. This, however, also has been unsuccessful. Recently English interests have had representatives in Eastern Ecuador.

DISCUSSION

CHESTER W. WASHBURN,* New York, N. Y. — What is the nature of the sediments on the east side of the Andes?

JOSEPH H. SINCLAIR. — The Cretaceous formations on the east side of the Andes Mountains consist of limestones, black shales, and sandstones. The sandstones are the lowest part of the Cretaceous seen by us and the limestones are the highest part. The Upper Cretaceous is covered by a widespread series of red beds, probably of Tertiary age, in which we found no fossils. The Red Beds are mostly sandstones and clays.

⁸ Sinclair Joseph H. and Wasson Theron (1923) Explorations in Eastern Ecuador. *The Geographical Review* (American Geographical Society). 13, 190.

*Consulting Geologist.

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**GEOLOGY OF GUAYAQUIL,
ECUADOR,
SOUTH AMERICA**

by

JOSEPH H. SINCLAIR

and

CHARLES P. BERKEY

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INTRODUCTION

In January and February 1921, the first-named author visited the city of Guayaquil and made a short geological examination of the hills in the northern part of the city. A few specimens of the rocks were brought to New York where thin sections were made and put through a petrographic and palaeontological examination. This paper is an outgrowth of these studies and is offered only as a small contribution to our knowledge of the geological conditions in this region.

The hills mentioned rise to an elevation of 300 feet above the Guayas River, the tidal stream on the right bank of which the city is situated, and form a part of a ridge which west of Guayaquil is known under the names, Cordillera de Chongón and Cordillera de Colonche. This ridge reaches the Pacific Ocean about 85 miles west of the city and according to Wolf ¹attains a maximum elevation of between 2000 and 2600 feet above the sea. It is broken at Guayaquil by the Guayas River but east of the river it is represented by five isolated hills which die out a short distance farther east into the low plains that reach to the base of the Andes Mountains.

That portion of the ridge in the northern part of the city is called “Cerro de Santa Ana” and on its summit is the city’s water reservoir. Just west of Guayaquil, in the slopes of the ridge are quarries which have furnished paving and building stones for many years.

The city itself lies for the most part on that flat flood plain of the river, but in the hills above mentioned, sedimentary rocks are everywhere exposed under conditions of folding, faulting and apparent lack of fossils which make their stratigraphical relations and age difficult of determination. In general, however, one can readily distinguish two clearly differentiated kinds of rocks, – the first composed of sandstones and shales, the second, of cherty rocks and limestones.

The only published account of these rocks known to us is by Theodor Wolf ²who has described them in terms of which the following is a partial translation:

“Beds of limestone, siliceous limestone, siliceous slate, silica, quartzite, yellow and green glauconitic sandstone and shale alternate in thin layers in a very remarkable manner. The limestone is rarely pure enough to burn for lime. It is almost always impregnated with silica which increases to the point where the limestone becomes a siliceous shale containing little lime. Most of the limestone is of white or yellowish color but there are varieties of siliceous limestone nearly black in color due to impregnation with bitumen. The beds of sandstone which alternate with the calcareous and siliceous strata are nearly always of dark greenish, yellow color. It appears that the sandstones predominate in the lower beds and the limestones in the upper. Stratification in many places is completely destroyed. The beds are also so steeply inclined and, in many places, so violently contorted and faulted that it is difficult to determine their strike.

Fossils have been found in only one locality, viz. in paving blocks in the streets of Guayaquil which contain remains of *Inoceramus* characteristic of the Cretaceous in other parts of the world. The greater part of these fossils is so crushed that it is difficult to recognize them. Professor Geinitz ³distinguished *Inoceramus latus* Sowerby among these however. I have searched in vain in all the quarries near Guayaquil for the place from which these paving stones came but could never find the bed or indeed fossils of any kind.”

¹ Theodor Wolf, Geografía y Geología del Ecuador, Leipzig, 1892

² Theodor Wolf, Geognostische Mittheilungen aus Ecuador, Neues Jahrbuch für Mineralogie, 1874, pp. 377-398

³ Wolf gives his authority for his statement on the fossils: Geinitz, Das Elbthalgebirge, 11, page 45, Table XIII, figs. 4 and 5. The only reference we have been able to find of this name is Hans Bruno Geinitz, Das Elbthalgebirge in Sachsen, Part 2, 11, vol. 20, Palaeontographica-Beiträge zur Naturgeschichte der Vorwelt, Cassel, 1872-1875, but in this there is no account of any fossils from Guayaquil. There is a description of the *Inoceramus* mentioned by Wolf but without any locality mentioned.

With the above account in mind, we also made a diligent search for fossils but with the same results as Wolf obtained. We were, however, rewarded by finding in the thin sections, fossil forms which are visible only under the microscope and these were identified for this paper.

Samples' description

The character of the cherty limestones of Guayaquil is fairly well shown by the following description of three typical samples:

- **Sample E-1** is a nearly white, dense rock, of micro-fine, almost amorphous, texture whose original structure was organic and which was subsequently modified somewhat by replacement and silicification. The essential primary constituents are microscopic organic forms, both carbonate and silica-bearing, including radiolaria and foraminifera. The introduced substance is chiefly silica. The rock was originally made up almost wholly of microorganisms, probably with both siliceous and calcareous shells and the rock still maintains this mixed composition. The matrix is largely carbonate but the principal fossil spots are siliceous, the two constituents being about equally abundant. It therefore is neither a simple limestone nor a true chert, but its origin and character are certain. Such a rock would probably be of simple silica or chert composition in some places and of almost straight carbonate composition in others with all sorts of gradation between. Its origin is organic and it is classified as a cherty infusorial and foraminiferal rock.

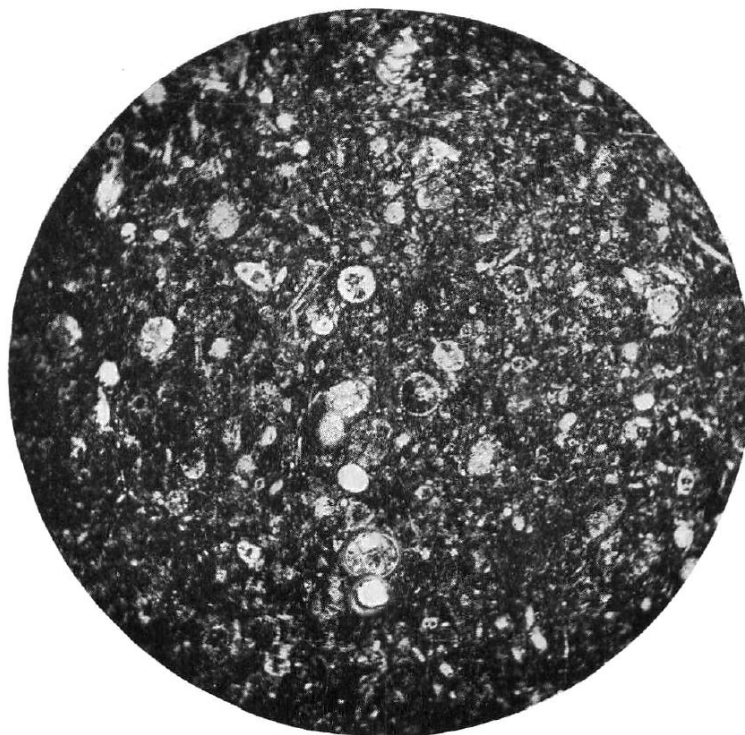


FIG. 1 – Photomicrograph of sample E-1 taken in plain light, magnification of about 30 diameters showing the micro-organisms that make up this rock.

- **Sample E-2** also is a nearly white, dense rock of microfine texture whose original structure was organic and which by secondary processes has been indurated. The primary essential minerals are microscopic forms including radiolaria and foraminifera, furnishing both carbonate and silica. It is of exactly the same origin as E-1 with the same intermixture of siliceous and calcareous constituents. It is perhaps a little patchier in the distribution of these constituents than E-1.

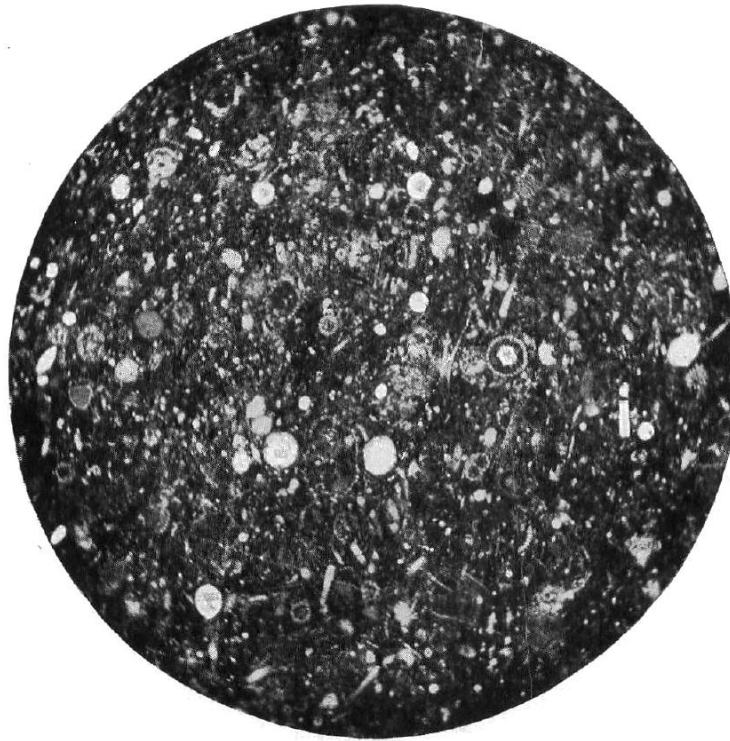


FIG. 2 – Photomicrograph of sample E-2 taken in plain light, magnification of about 30 diameters showing the fine structure and the microorganism makeup of the rock.

- **Sample E-3** is a gray-colored rock of sedimentary appearance whose texture varies from fine to medium. Its original structure was chiefly clastic but it has now a secondary veined structure. The primary essential minerals are quartz and feldspar fragments, carbonate and fossil forms of considerable variety, including foraminifera. This rock differs from E-1 and E-2 in that it carries a large amount of angular fragmental mineral material. Most of these are practically fresh feldspar fragments and this leads to the belief that the fragments are not of ordinary weathering or disintegration origin but may be of ash or volcanic origin instead. There are other mineral grains of much less prominence lending support to the same interpretation. The groundmass or matrix is chiefly carbonate carrying an abundance of minute fossil forms, the variety of which is somewhat greater than in E-1 and E-2. The rock is in part organic, therefore, and in part clastic but it doubtless is a member of the same series of sedimentary accumulations represented by E-1 and E-2 except that the local conditions were somewhat different at the time this one was deposited. It is therefore classified as an ash bearing foraminiferal lime rock.



FIG. 3 – Photomicrograph of sample E-3 taken in plain light, magnification of about 30 diameters showing the mixed composition of the rock. The angular clear grains are chiefly fragments of feldspar and quartz. The matrix is an aggregate of carbonate and finer fragments and the large regular structure is of organic origin.

These three samples illustrate the range from a cherty infusorial rock with both carbonate and chert as prominent constituents, to a carbonate rock with micro-organic and fresh mineral fragments in abundance. It is evident that they are essentially accumulations of microorganisms in which radiolaria and foraminifera dominate and that they form extensive accumulations of mixed siliceous and carbonate composition. With these beds, however, are associated clastic materials in varying proportions and probably of considerable range of composition.

Fossils' identification

The photomicrographs show plainly the presence of many forms which Dr. H. N. Coryell of Columbia University was able to identify as follows:

- E-1 (fig. 1.) *Orbulina universa*
 Ostracoda
Globigerina bulloides
- E-2 (fig. 2.) *Orbulina universa*
- E-3 (fig. 3.) *Lituola (Haptophragma) irregularis*
Textularia
 Gastropoda
 Rotalia

Dr. Coryell writes: "These forms are consistent for Cretaceous age, some of them being equally appropriate for the Eocene. On the whole we judge them to be Cretaceous."

The fauna consists of single-to-many-chambered lime secreting foraminifera and single-chambered silica secreting radiolaria. Animals of this nature are pelagic and move about near the surface of the sea in large colonies. The siliceous radiolaria are found in both deep and shallow waters; the calcareous foraminifera and siliceous sponges are inhabitants of shallow seas.

CONCLUSIONS

We know of no other occurrence of cherts in Ecuador except in the Santa Elena peninsula about 85 miles west of Guayaquil. These have been described in a previous paper⁴. In all essential respects the Guayaquil and Santa Elena cherts are petrographically similar. They have the same general origin and are in essentially the same present condition and have gone through the same sort of life history. The organic forms are similar at least in major characters. We are as much impressed by the similarity of origin, history and condition as by anything else. They are alike in all these points even to the presence in some of the beds of angular fragments of fresh, clastic minerals thought to be ash, and in the matter also of change in quality of vein-filling or healing of the breccia in different stages of deformation.

The calcareous specimens of the Guayaquil and Santa Elena districts contain a foraminiferal fauna of identical genera and related species indicating that the beds from which these specimens were collected are of about the same age, and that they were deposited under very similar conditions. Judging from the microscopic forms in the two localities, it is concluded that they are all consistent for Cretaceous age.

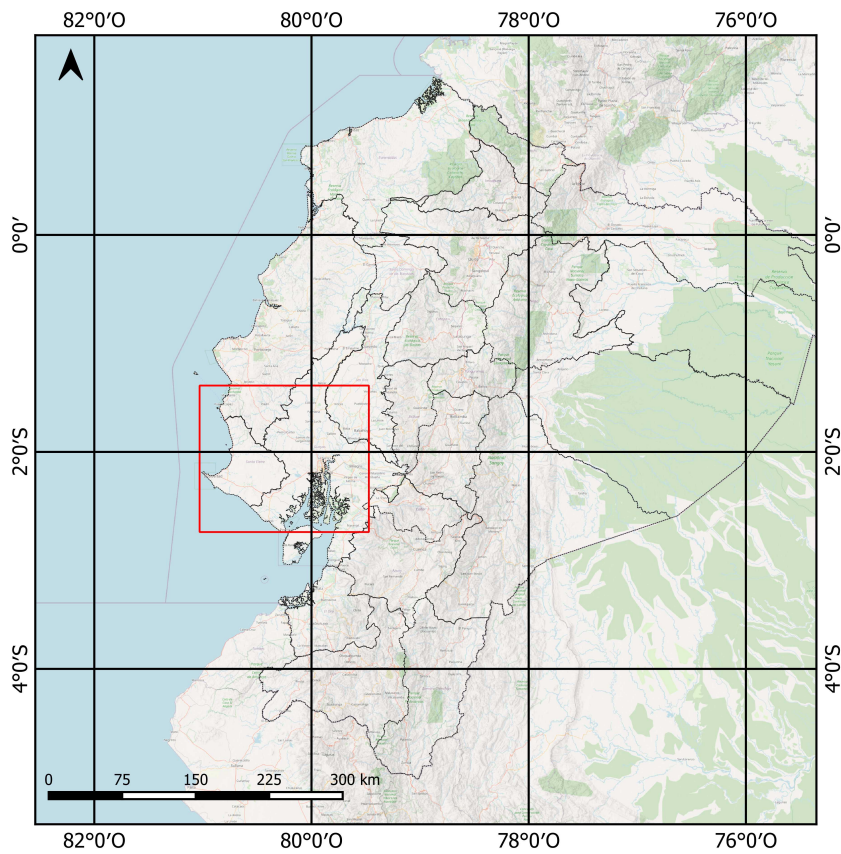
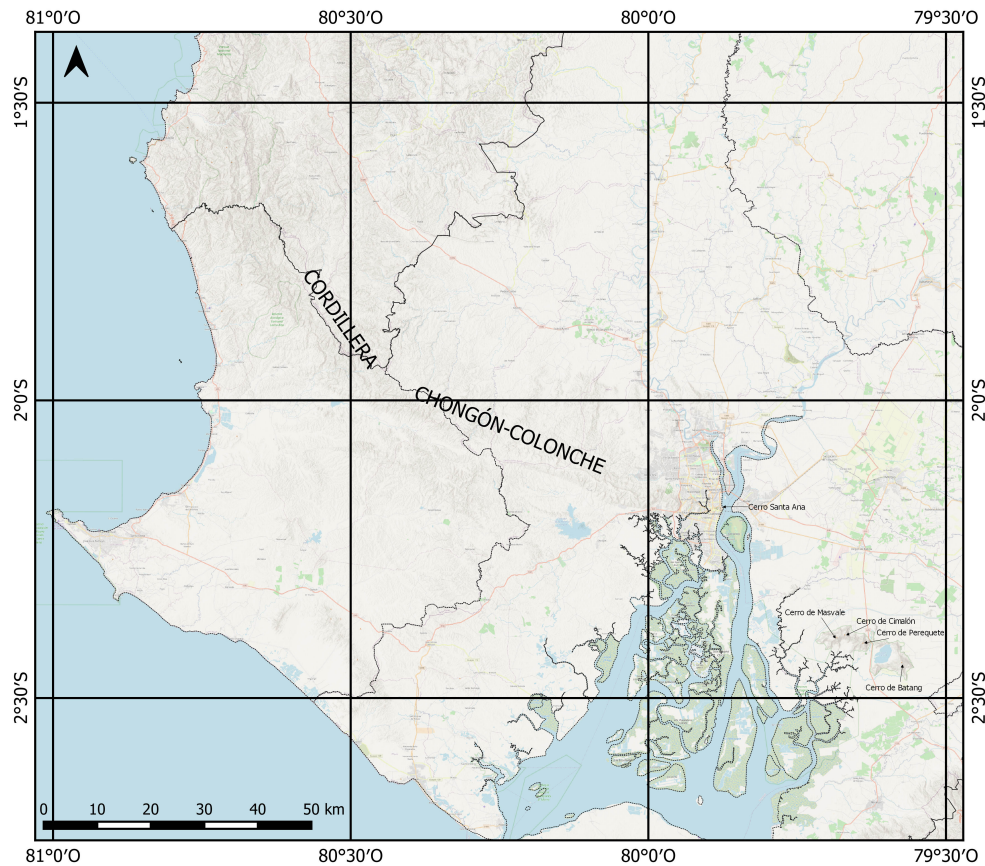
In a forthcoming paper, on the geology of the Amazon Plain east of the Andes in Ecuador⁵, there will be described the discovery of a widespread series of Upper Cretaceous limestones lying nearly horizontal and undisturbed at the base of the Andes Mountains. These are highly impregnated with bitumen and collections of many fossil forms leave no doubt as to their Upper Cretaceous age. This section is the reference point for Ecuadorian stratigraphy and it would appear reasonable to conclude that the Santa Elena cherts and the Guayaquil rocks are representatives of these limestones west of the Andes. The bitumen content, apart from the fossiliferous evidence, is strikingly noticeable.

New York City and Berkeley, California.

⁴ Joseph H. Sinclair and Charles P. Berkey, Cherts and Igneous Rocks of the Santa Elena Oilfield, Ecuador. Trans. Amer. Inst. Mining and Metallurgical Engineers, Canadian Meeting, Montreal, August, 1923, 17 pages.

⁵ The geographic features of this region have been recently described by Joseph H. Sinclair and Theron Wasson in a paper entitled: Explorations in Eastern Ecuador, The Geographical Review (American Geographical Society) New York, April, 1923, pages 190-210.

Location Map



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**GEOLOGICAL EXPLORATIONS
EAST OF THE ANDES IN ECUADOR**

by

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and

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ABSTRACT

An area of 8000 square miles, lying east of the Andes in Ecuador, was explored in 1921. The old Indian towns of Archidona, Tena, and Napo are in the northern part; Macas, the largest settlement in the Oriental region, is at the southern extremity of the area. Astronomical observations were made as a check on the plane-table traverse, which was carried over all routes of travel. Collections of fossils, mostly from the vicinity of Napo, establish one horizon of Turonian (Eagle Ford-Benton) age, and a second of middle Albian (mid-Comanchean) age. Unfossiliferous red beds occur above this Cretaceous section, and, below it, are sandstones and volcanic rocks. The Napo Cretaceous beds are petroliferous. Cretaceous rocks east of the Andes have been described from Colombia, Venezuela, Perú, Bolivia, and the Argentine Republic, but this is the first description of such rocks from eastern Ecuador.

INTRODUCTION

Basis of the paper

This paper presents an account of observations made by the authors while engaged in geological work in eastern Ecuador for the Leonard Exploration Company, through whose courtesy it is published. Five months during the latter part of the year 1921 were spent in the field.

History of explorations

So energetic was the Spanish conquest of Perú that seven years after the execution of Atahualpa, the last Inca king, the Spanish sent an expedition into what is now eastern Ecuador. Gonzalo Pizarro, brother of Francisco Pizarro, the famous conqueror of Perú, marched northeast from Quito in February, 1541, descending the valley of the Río Coca. Although many died from famine and disease, a few men under Orellana drifted down the Napo and Amazon to the Atlantic.

Many since that time have crossed this area: travelers, explorers, and priests. The striking thing about all these journeys is the small amount of geographic knowledge and the entire lack of geologic knowledge recorded.

Alexander von Humboldt¹, who journeyed in the Andean Highland in 1801-1802, climbed the volcanic peaks around Quito but did not descend the eastern slopes of the Andes. He is the first, however, to record Cretaceous rocks in the Andean highlands.

In 1867 James Orton of Rochester, New York, made a trip across the Andes from the Pacific side and descended the Río Napo to the Amazon and thence to the Atlantic. He published an account of his trip in book form², and also a record of his physical observations³ which were of great scientific value. He carried two mercurial barometers, a Wollaston boiling-point apparatus, and thermometers.

¹ Alexander von Humboldt (1837) *Geognostische und Physikalische Beobachtungen über die Vulkane des Hochlandes von Quito. König Preuss-Akademie der Wissenschaften Berlin, Verhandlungen*, February 9, 1837.

² James Orton (1870) *The Andes and the Amazon*. New York: Harper Brothers. 356 pages.

³ James Orton (1868) *Physical Observations on the Andes and the Amazon. American Journal of Science*, Vol. 46. New Haven, pp. 203-213.

The best map of Ecuador was prepared by Theodor Wolf, a German, who taught for thirty years at the University of Quito. In 1892 his map was published in Leipzig at the expense of the Ecuadorian government. A small-scale edition in atlas form was prepared by Felicísimo López in 1907.

The authors have previously published a map ⁴of the area explored by them. It is the first map of this area based on a plane-table survey. It shows for the first time the exact location of the volcanic peak of Sumaco and the details of the Río Napo from the town of Napo to the mouth of the Río Coca.

Acknowledgements

Dr. José Luis Tamayo, president of Ecuador in 1921, received the writers in Quito and gave them letters to government officials and others which were of great assistance in traveling through the Oriental region.

Mr. Nicolas G. Martínez, of Ambato, arranged for the special train from Ambato to the end of the railroad line at Pelileo. He also furnished copies of maps of the Curaray Railway Survey which were used in starting the surveys east of the Andes. Mr. Manuel I. Rivadeneyra, of Napo, furnished Indian carriers and acted as interpreter among the Indian tribes. The success of the expedition was partly due to his good management. Governor Burbano de Lara, of the Oriental region, gave official welcome to the party at Tena. The Dominican Fathers at Canelos will always be remembered for their hospitality and assistance, as will also the government officials and town council at Macas under the command of Manuel J. Bejarano. The end of the journey at Riobamba was made pleasant by the friendly welcome of Colonel Enrique Rivadeneyra. Special mention should be made of the assistance of representatives of the Leonard Company in Ecuador.

THE AREA EXPLORED

The area explored (Fig. 1) lies east of the Andes between 0°30' and 2°30' south of the equator and between meridians 77°00' and 78°10' west of Greenwich. This area extends approximately 100 miles eastward from the foot of the Andes and 170 miles north and south. The old Indian towns of Archidona, Tena, and Napo are in the northern portion of the area. The town of Macas is at the southern extremity.

Route of travel

Entrance to the region was from the Pacific seaport of Guayaquil by rail over the American-built railroad to Ambato, which is on the main railway line between Guayaquil and Quito. Ambato is on the central plateau of the Andes, 196 miles by railroad from Guayaquil, and is 8435 feet in elevation. At Ambato another railway line was followed to its terminus at Pelileo, 21 miles east. Here Quechua Indians from the Oriental region transferred all baggage to back packs, and the journey down the Río Pastaza was resumed on foot. At Mera on the Río Pastaza, 56 miles east of Ambato, the survey was started. It followed an obscure Indian trail northeastward to the valley of the Río Anzu, which was descended to Napo, a small settlement on the Río Napo, 48 miles from Mera. Here headquarters were established for the exploration of the northern portion of the area.

⁴ Sinclair H. Joseph and Wasson Theron (1923) Explorations in Eastern Ecuador. *Geographical Review*, Vol. 13. April 1923.

From the town of Napo a stadia survey was made down the Río Napo to the mouth of the Río Coca, a distance of 98 miles.

Returning to Napo, the expedition traversed the Papallacta trail, which is the old route from Quito to Napo, with side trips on the rivers which were crossed. This trail was followed a distance of 29 miles from Napo to the foot of the Cordillera Guacamayos, a low spur running east from the Andes. After another return to Napo, a trail was cut and surveyed southward through the forest to Canelos on the Río Bobonaza, 56 miles from Napo. Then the traverse continued southward from Canelos on old Indian trails across the Río Pastaza to Alpico on the Río Palora, and farther south to Macas on the Río Upano, 126 miles by traverse measurement from Napo. At Macas the surveys terminated and the return to civilization was made up the Río Upano to its headwaters at the summit of the Andes (map, Fig. 1) and down an affluent of the Pastaza to the railroad at Riobamba, a city on the Andean plateau, 35 miles south of Ambato, the starting-point. The approximate distance covered on foot and by canoe, counting some back-tracking in the vicinity of Napo, was 600 miles.

Methods of survey

In the absence of any accurate map of the Oriental region, the boundaries of the concessions examined had been defined in terms of latitude and longitude. In order to locate these the expedition carried, besides the Gurley alidade and plane-table outfit, two accurate watches and an engineer's transit with vertical arc, with which observations for azimuth, latitude, and longitude were made.

The two watches were compared with the ship's chronometer on the voyage from Panama to Guayaquil, and one was set to Greenwich mean time and accurately rated for daily variation. These watches were carefully packed and transported across the mountains. At Mera the first observation was made on the sun at noon for longitude, but clouds prevented any check by star observations. Repeated observations on the sun established the longitude at Napo as $77^{\circ}49'$ west of Greenwich. Observations for longitude at other places were not taken because of the increasing errors in the time carried by the watches, but this was unnecessary, as all other points were tied to Napo by the plane-table traverse.

Latitude was determined at Napo, the mean of many star observations being $1^{\circ}03'$ south. At other points along the survey where weather conditions permitted, observations were made for latitude as a check on the plane-table traverse.

Starting at Mera where the Río Pastaza emerges from the Andes, a plane-table traverse was run over all the route as far as Macas. A 300-foot cotton tape coated with paraffin was used on the forest trails. A new tape was made every week. Direction was obtained by sighting on the position of the man ahead as determined by the sound of his voice. Corrections for lack of alignment of the tape were made on the ground. On open rivers like the Napo a more accurate survey was made by the stadia method with the plane table and telescopic alidade.

The survey of the route of travel was mapped on a scale of 1:48000. A smaller map on a scale of 1:480000 was also constructed in the field in order to triangulate the mountain peaks. A simplified form of this map is the one published in Figure 1.

Elevations were established with aneroid barometers. The curves of daily variation which were made at several points along the route of travel showed very uniform atmospheric conditions from day to day. High barometer at nine in the morning is followed by a slowly falling barometer until four in the afternoon, when the maximum low is reached. This maximum low is generally followed by a gentle rain which falls for two or three hours. Barometric curves at several points in the area are so nearly alike that the same correction table can be used for all stations.

PHYSIOGRAPHIC DIVISIONS OF THE ROUTE

Pacific Coastal Plain

In order to reach the Amazon plain in which explorations were carried on, the Pacific coastal plain and the Andes Mountains were crossed. The coastal plain is about 50 miles wide, is low-lying, and is covered with tropical vegetation, with the exception of plantations of sugar cane and cacao here and there. The streams are short and torrential, emerging suddenly from the Andes where they drop débris in the form of alluvial fans and cones. Over the lowlands they are sluggish and muddy, following meandering courses.

Guayaquil is the only large seaport in Ecuador. It is situated on the Río Guayas near its junction with the Gulf of Guayaquil, which is virtually an estuary of the Río Guayas. From Guayaquil the railroad crosses the coastal plain and then abruptly rises to the summit of the Andes at an elevation of 10000 feet. A vertical distance of about 9000 feet is negotiated by rail in 20 miles of direct line, although the course of the railroad is several times that distance. The vegetation changes suddenly at about 6000 feet from tropical to semi-arid.

Andes Mountains

The Andes Mountains consist of a plateau about 9000 feet in elevation, from which rise many volcanic peaks. These have been described as forming an eastern and western cordillera, but topographic studies show no such regularity. These peaks, however, divide the plateau into basins, in one of which lies the town of Ambato. The plateau region is treeless and semi-arid, and the volcanic peaks are covered with perpetual snow. On the lower slopes of the mountains there are considerable areas under cultivation, and some of the bottom lands are irrigated. The climate is temperate and much fog exists at certain seasons.

The Ambato basin is drained by rivers flowing into the Amazon. The Río Patate flowing from the north, and the Río Chambo from the south, unite near Baños to form the Río Pastaza. Both these tributaries are of moderate size, and at the junction where they join to form the Pastaza they are deeply intrenched in volcanic ash.

The most prominent characteristic of the Andean uplift in Ecuador is its narrow base and precipitous sides, the mass being less than 90 miles wide at the base and 40 miles wide at the top. The plateau summit is about 9000 feet in elevation and from this general level rise volcanic cones to elevations of 18000 and 20000 feet. Among the more prominent peaks are Chimborazo, Cotopaxi, Tunguragua, and Sangay, the cones of Cotopaxi and Sangay being particularly symmetrical. The sides of the volcanic peaks are covered with extrusive volcanic débris, much of the material on the plateau at their base being in the form of pumice. The general aspect of the slopes of these volcanic peaks gives the impression of very recent volcanic activity.

The Pastaza Valley

The Río Pastaza formed by the junction of the Chambo and the Patate, 25 miles east of Ambato, flows due east, cutting deep into the eastern slope of the Andes, and is a natural route of travel from the highlands to the Amazon plain. The valley is deeply intrenched in volcanic débris east of Ambato, and on the northern slopes of Tunguragua is cut through recent lava flows. From the junction of the Chambo and Patate, at an elevation of 6300 feet, the river descends to 3800 feet at Mera, 31 miles farther east, where it emerges from the wall of the Andes. Five miles east of Baños is Agoyán Falls, 200 feet high, where the river plunges over a lava bed. Below these for several miles small waterfalls enter the gorge through hanging valleys.

The Pastaza as it emerges from the mountains changes into a braided stream of swift current, in time of flood transporting much material. Great boulders are carried or rolled along the bottom and their grinding can be heard some distance from the stream. After leaving the Andes the Pastaza flows southeastward across the south-central part of the area under discussion to join the Amazon, 250 miles west of Iquitos, Perú. Looking from a point on the east slope of the Andes out on the lowland extending eastward from the base of the mountains, one gets the impression, aided by the thick forest cover, of a uniformly sloping smooth plain. An examination of this, however, shows it to be a region which for 100 miles from the base of the Andes slopes from 4000 to 1000 feet above the sea and is made up of more or less dissected interstream areas and river valleys, some of which are 1000 feet below the interstream summits.

GEOGRAPHY OF THE REGION EXPLORED

Drainage

The region explored on this eastward-tilted plain may be divided into a northern and a southern area, such division being made on the basis of the two main lines of drainage. The northern area is drained by the Río Napo and its tributaries. The Río Anzu, the principal tributary of the Napo, flows from the vicinity of Mera, 40 miles northeast, to the village of Napo, where it joins the Río Napo. All previous maps showed this river as flowing due east from the foot of the Andes. The Río Napo has its source in the belt of heavy rainfall, and is a torrential stream subject to sudden floods. At Napo the river is 300 feet wide, with banks of limestone. Below Napo the stream becomes progressively wider, with many side channels, the banks being lower and made of alluvium. In this lower section the stream is excessively braided due to the lessened gradient and to the material carried in flood time, which, as the current slackens, is deposited in the channels, forcing the water to find new courses. At the junction with the Coca the Napo is 2000 feet wide and here flows in a single channel, is more sluggish and meandering, carrying mud and silt rather than sand and gravel.

The area explored north of the village of Napo is drained by the southward-flowing Misahuallí and its tributaries, the Jandachi and the Hollín. These streams are all similar to the upper course of the Napo and all drain into it. The northern boundary of this area is formed by a mountain ridge, the Cordillera Guacamayos, extending eastward from the Andes as a spur. A few miles east of the termination of the Cordillera Guacamayos stands Cerro Sumaco, an isolated volcanic peak with an elevation of about 12700 feet, which seems to rise out of the Amazon lowland. This peak was located and its elevation determined for the first time by this expedition. Also in this area north of the Napo is the Cordillera Galeras, whose peaks were located by triangulation from the Río Napo survey. They rise to an elevation of approximately 6000 feet. They were not explored.

The two principal southern tributaries of the Napo, the Arajuno and the Curaray, were crossed during the survey from Napo to Canelos. These streams rise near the headwaters of the Anzu in the highlands east of Mera. Their courses were not surveyed, but where crossed they are small, clear streams in well-defined channels. The stream divides rise to nearly 1000 feet.

The southern area is drained by the Río Pastaza, which, as previously noted, flows southeastward after emerging from the Andes at Mera. Its northern tributaries, the Villano, Bobonaza, and Pindo, all rise in the high land east of Mera. At the mouth of the Río Pindo the Pastaza is a rapid stream about 600 feet wide at low water. South of the Río Pastaza the first tributary is the Río Palora, which at Alapicos is a rapid stream-flowing between banks 100 feet high. Between Alapicos and Macas the trail surveyed passes close to the base of the Andes and through a region of torrential rains. Many small, rapid streams flowing eastward were crossed. They carry no sediments, but flow over grassy slopes between low banks. The sheets of water have not collected into well-defined channels.

The trail from Macas to Riobamba on the Andean plateau followed the Río Upano to its source in lakes high in the Andes. The river is in a deep gorge on the eastern slope of the Andes, and, like the valley of the Pastaza, makes a natural route from the highlands into the Oriental region.

Forests

The forests are limited entirely to the lower slopes of the Andes and to the lowlands at the east. The highlands of the Andes, due to the lack of rainfall, are treeless and are called *páramos*. No breaks occur in the extensive forests east of the Andes except in the neighborhood of the small settlements where a few acres are cleared.

Climate

The rainfall is exceptionally heavy on the east slope of the Andes, but light on the plateau. Its greatest amount occurs on the immediate east wall of the mountains, where the moisture-laden air begins to ascend. What precipitation reaches the lofty elevations of Chimborazo and other peaks which rise more than 20000 feet above the sea occurs as snow and ice. Extensive glaciers and snow fields are located on Antisana, Chimborazo, and other peaks. The snow line is about 15000 feet above sea-level. The rainfall at Puyo at the eastern base of the Andes, at an elevation of 3200 feet, has been estimated at 150 inches per year.

In the area explored east of the Andes between elevations of 1400 and 2000 feet the temperature ranged from 66° to 82° Fahrenheit.

Inhabitants

The Andean plateau is well populated; the Amazon lowlands have very few inhabitants. The Indian aborigines east of the Andes form the main part of the population. The Indians north of the Pastaza live close to the few white settlements and speak the Quechua language. South of the Pastaza dwell Indians who are entirely independent of white masters and speak the Jivaro language. The latter are noted for their head-hunting customs, which have been described by several writers⁵.

⁵ De Graff F. W. Up (1923) The Head Hunters of the Amazon. New York. 337 pages.

Settlements

Settlements in the Oriente are few and located along streams, which are the chief means of communication. The settlements consist of a few white families who have the loyalty and service of many Indians living close by. At Napo there are four houses inhabited by white Spanish-speaking people, among whom is Manuel Rivadeneyra, a true pioneer. It was once a mission station with a larger population. Tena, 4 miles north of Napo, is somewhat larger, since it is the headquarters of the governor of the Oriente. Archidona, near Tena, was founded soon after the Spanish conquerors arrived in Ecuador and became the headquarters of the early missionaries. Canelos is the principal settlement between the Napo and the Pastaza. It was also founded as a Catholic mission shortly after the Spanish conquest of Ecuador. Today, after several periods of abandonment, it is again a mission center with two Dominican fathers in charge. Macas, located in the southern part of the area, is much the largest town in the Oriente, having a population of about 600. In 1921 it had a Protestant mission in charge of Mr. and Mrs. Oleson, and a Catholic mission. The village of Macas is so isolated, one wonders at its existence. There is no other settlement between it and the top of the Andes. It takes seven days of tedious traveling on foot along muddy trails to reach the nearest settlement on the upland.

The Indians have no villages as such. The Jivaros approach more closely a social organization in that sometimes they live in large houses containing several families.

STRATIGRAPHY

Andean crystalline rocks

The trail down the Pastaza from Ambato to Baños passes through a region of recent volcanic activity, and most of the surface exposures are made up of extrusive material. Near Pelileo some rhyolite was observed.

From the junction of the Chambo and Patate to Baños the south wall of the Pastaza canyon is made up of lava flows from the volcano Tunguragua. In some places basaltic columnar structure is well developed. Schists, gneisses, and granites are exposed along the north side of the river above Baños to Mera. Granites and rhyolites occur above Mera. These rocks, which form the core of the Andes of Ecuador, were not studied in detail. They are unquestionably older than the sedimentary series east of the mountains.

Napo region – Sedimentary section

The best sedimentary section exposed in the area is in the vicinity of Napo. The beds outcrop in an area whose dimensions are 25 miles north and south by 10 miles east and west, and whose elevations range from 1500 to 2000 feet. The outcrops are along streams where the forest cover has been cut away by stream action. In the absence of any geological information on the region, notes were taken on all rocks examined and collections of fossils were made. As the work progressed it was possible to make up a column and determine age and extent of beds.

Misahuallí basalts and tuffs

The lowest rocks observed in the Napo region are on the Río Misahuallí, 6 miles east of Tena. They consist of basalts and altered extrusive igneous rocks overlain by tuffs. The basalt is predominantly green or dark brown, and in its altered condition has the appearance of sedimentary rock. The greatest thickness observed is about 150 feet. These igneous extrusives probably represent local flows interbedded with the sediments. The tuffs overlying the basalt are gray and pink in color and are in sharp contrast to the overlying sandstone. The thickness was not determined, but it is probably not more than 100 feet.

Hollín sandstone

Overlying the basalts and tuffs of the Río Misahuallí is a clean, fine-grained quartz sandstone with a thickness of 400 feet. It is well exposed along the Río Hollín, where cliffs more than 100 feet high are found. No basal conglomerate was found at the contact with the underlying igneous rocks; neither was there any inclusion of igneous material in the overlying sandstone. Near the confluence of the Río Tena and the Río Hollín is a thin bed of unfossiliferous black shale near the middle of the sandstone. The exposures of Hollín sandstone are near the axis of the Napo anticline, where only basalts and tuffs were seen to underlie it. It is probable that the igneous rocks are local flows and that older sedimentary beds exist beneath them.

The Napo limestone

Overlying the Hollín sandstone is a series of limestones and black shales 1500 feet thick. The forest cover makes the estimation of thickness very difficult. The best section of these beds exposed in the area is along the Río Napo eastward from the town of Napo. From the crest of the low anticline just west of the town beds of limestone and shale dip 6° - 10° E. The strike is $N45^{\circ}$ E. At some places the Río Napo flows along the strike of the beds. A thick limestone member outcrops from the crest of the anticline just west of Napo to a point one mile downstream (Fig. 2), where black shales are found overlying it. This limestone is dark gray and highly fossiliferous, at places being almost a shell conglomerate. It weathers into large blocks. The lower beds merge into a shale which is exposed at low water on the anticlinal axis just west of Napo. Here a bone bed is found carrying fish vertebrae and teeth along with ammonites. This bone bed is the lowest exposure in the Río Napo section. The black shales carry many fossils, the most prominent being *Inoceramus labiatus*. Flat lens-like inclusions of limestone are in the upper layers of this shale. The highest Napo limestone beds are 6 miles below Napo, at the rapids called Molino de Latas. Here they dip into the river and a short distance downstream they are covered by red beds.

Other sections of the Napo limestone were studied north of Napo (Fig. 3). The contact of the Napo limestone with the underlying Hollín sandstone is seen about 5 miles east of Tena, along the Río Tena and along the Río Hollín east of Archidona. The black shales are also exposed east of Tena. The section along the Río Tena is on the west flank of the anticlinal axis, which passes just west of the town of Napo.

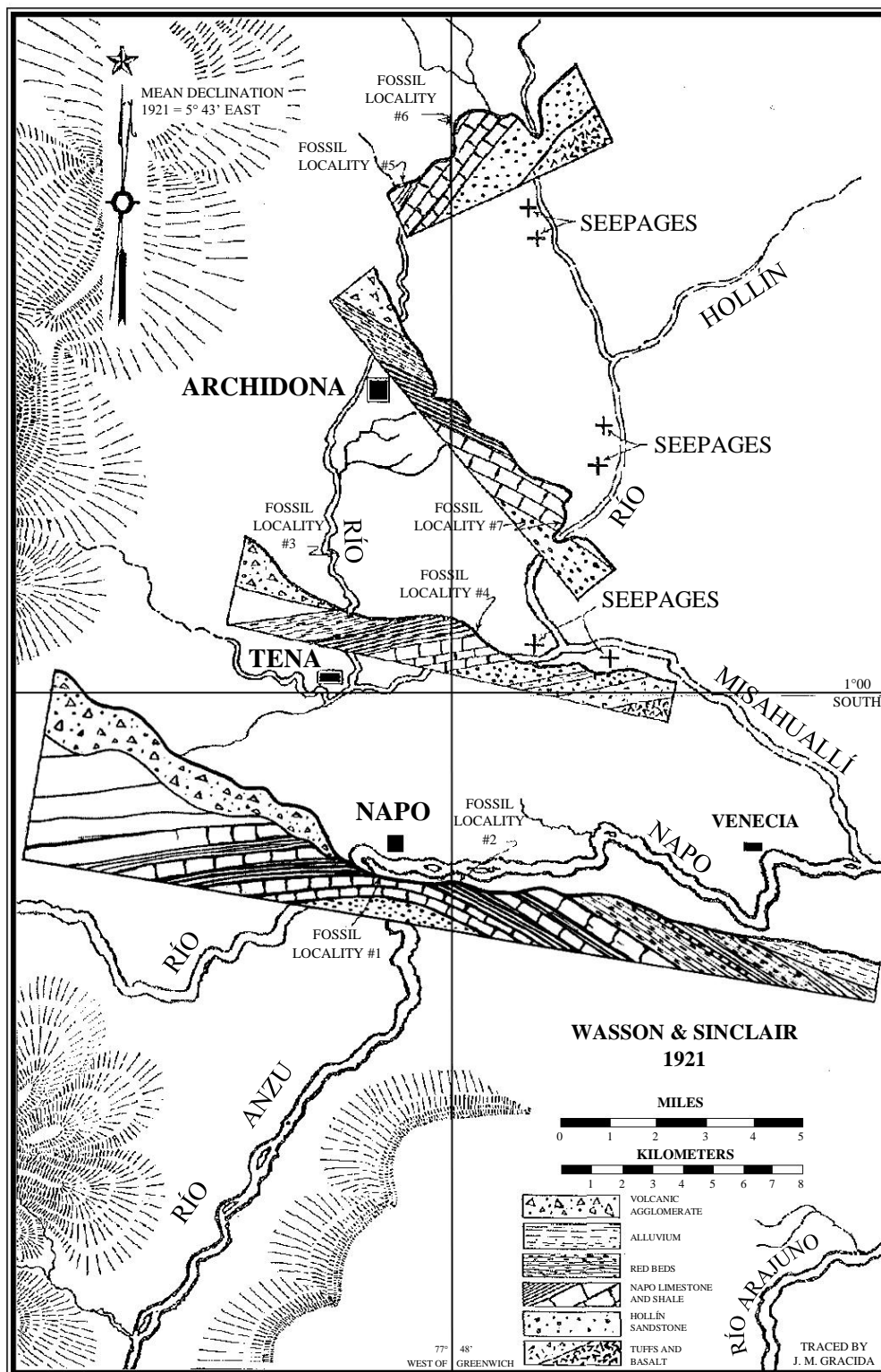


Fig. 2 – Map of the Napo area showing sections of the Napo limestone, fossil localities, and seepages.

The age of the Napo limestone has been determined, from the fossils collected, as middle Comanchean to Upper Cretaceous, middle Albian to Turonian of the European section. These fossils are largely of Turonian age, equivalent in the United States to Eagle Ford or Benton of the Texas and Rocky Mountain sections, respectively. John B. Reeside Jr., who examined these fossils, called attention to Albian forms comparable to the mid-Comanchean or Fredericksburg of Texas occurring below the Turonian without any evidence of Cenomanian between. It is possible that Cenomanian beds exist, but that no fossils were collected from them.

The best Albian fossils came from the Río Hollín, east of Archidona, from beds just above the Hollín sandstone. The Napo beds all yield Turonian forms, the highest Turonian coming from limestone beds east of Morales' house on the trail from Archidona to Quito. A collection of fossils from the trail crossing Ursuyacu Creek, 9½ miles north of Napo, shows Albian forms, but field evidence was lacking to show the relation of the highly tilted shales of this locality to the rocks of the Napo and Archidona areas. Further work in the region may make it possible to divide the Napo limestone into separate formations. For the purposes of this first report the Napo limestone is understood to represent the limestones and black shales which lie between the sandstone of the Río Hollín and the red beds at Venecia on the Río Napo. It is interesting to note that James Orton⁶ referred to the Napo rocks as "dark slates gently dipping east", and made no mention of the Cretaceous fossils (Fig. 4).

Fossil localities. Fossils of the Napo limestone were collected from the following eight localities (Fig. 2):

1. An outcrop of shales and limestones on the left bank of the Río Napo about ¼ mile above the village of Napo at the crest of the broad anticline, where the strata are nearly flat and unquestionably in place.
2. Left bank of the Río Napo, 1 mile below the village of Napo, from black shales and limestones in place and striking N45°E. and dipping 8°SE.
3. The Río Misahuallí, about 2 miles above its confluence with the Río Tena.
4. In the Río Misahuallí, between the mouth of the Río Tena and the mouth of the Río Hollín, where black shales and limestones occur partly in place and as great blocks fallen down into the narrow canyon from the cliff walls.
5. Trail leading east from the Quito road at the house of José Morales, north of Archidona, to the Río Jandachi (locality 6). The specimens were from a yellow sandy horizon near the top of the Napo limestones. Locality is 1¾ miles northeast of Morales' house.
6. Río Jandachi, six miles northeast of Archidona in a narrow canyon with vertical cliff walls. Horizon should be near the base of the Napo limestones as the underlying sandstones form cliffs at the water surface.
7. Río Hollín, 3 miles southeast of Archidona, about ½ mile below a seepage of tar in the river bed at the base of a cliff. At this locality the canyon is very narrow with nearly perpendicular walls. The blocks of limestone from which collections were made represent horizons in the cliffs.
8. Quito trail at the crossing of Ursuyacu Creek, 9½ miles north of Archidona.

⁶ James Orton (1870) *The Andes and the Amazon*. New York: Harper Brothers. 356 pages.

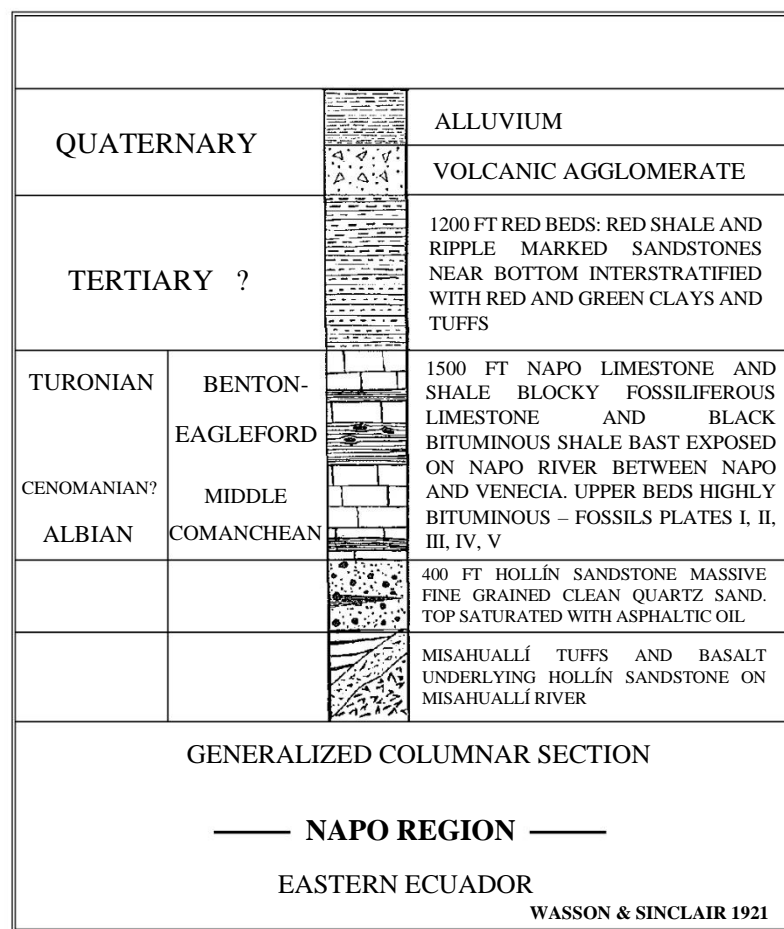


Fig. 3 – Refer to Plates 9, 10, 11, 12 and 13 for fossils

REPORT ON THE FOSSILS

John B. Reeside Jr., of the U. S. Geological Survey, examined the fossils collected and made the following report, accompanied by the illustrations shown in the succeeding plates. The fossils examined are deposited in the U. S. National Museum at Washington.

This collection of fossils contains a good representation of two very distinct Cretaceous faunas, one of Turonian age and one of middle Albian. The Turonian fauna in turn is represented by what I take to be two facies, for while the species and the matrix differ, the age is not very different.

The fauna in a hard limestone from the vicinity of the village of Napo (Fig. 2, localities 1 and 2) is composed of species universally accepted as characteristic of the Turonian, equivalent in a general way to that of the Eagle Ford shales of the Gulf region and the Benton formation of the western interior of North America. A very similar fauna is known from Perú, Colombia, and Venezuela.

The fossils in the hard gray limestone from the localities on Río Misahuallí (localities 3 and 4) include Albian and probably Turonian.

The small lots in gray limestone from Río Jandachi I believe to be Turonian. The large lot in a yellow sandy matrix that looks like a leached calcareous rock, from the locality on the trail east of the house of José Morales (locality 5), I judge also to be Turonian. There are several species present whose closest relationships are with characteristic Turonian forms, though a few have close relations with Cenomanian or Senonian species. Others are long-ranging and not definite in their testimony. The lot has only one species in common with those from the vicinity of Napo and differs much in lithology, but there can hardly be any great difference in age.

The lots from Río Hollín southeast of Archidona (locality 7), are mostly in a dark-gray hard limestone and contain chiefly species universally accepted as characteristic of the Albian, particularly the ammonites. Some authors have called this fauna Vraconian, or late Albian, but Vraconian is better restricted to the very latest zones of the Albian. The genera *Brancoceras* and *Oxytropidoceras* are middle Albian. *Oxytropidoceras* is found in the Fredericksburg group of Texas. There are, however, also several specimens of black shale and gray limestone with characteristic Turonian species, showing that both the Albian and Turonian horizons are present in the section. The Albian zone is equivalent to some part of the middle Comanchean of the Gulf region of North America, and its fauna is well known at many localities in Perú and Colombia.

The lot from Ursuyacu Creek at the crossing of the Quito-Napo road (locality 8) appears to be Albian, though I do not feel certain of the age in view of the absence of the more distinctive species.

The lot without specific locality assignments contains both Turonian and Albian species.

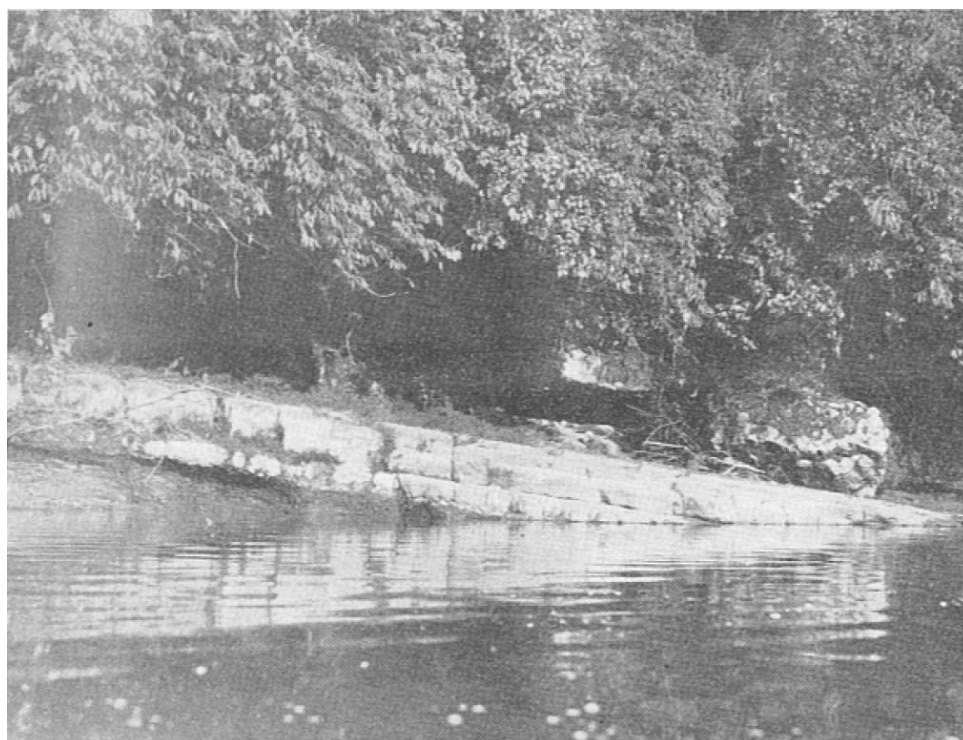


Fig. 4 – Napo limestone dipping downstream, located on the bank of Río Napo

As these statements indicate, the Napo limestone series includes at least two very distinct elements: one of Turonian age and one of Albian age. Between them should lie any deposits representing Cenomanian time. Some of the fossils included in the lists are known in the Cenomanian; some of them, indeed, are used, at least locally, as diagnostic of it. Most of these species, however, have been identified through a considerable stratigraphic range when their entire geographic distribution is taken into account, and are therefore of doubtful value here. I do not see any clear evidence of the presence of a Cenomanian fauna in the collection in hand, though it might very well be represented in the Napo limestone, and through the unavoidable accidents of collecting not have found its way into the collections.

It is notable that the succession of beds in eastern Ecuador is much like that reported from central Perú. Schlagintweit ⁷cites a generalized section in which light-colored marly limestone assigned to the Albian is overlain by a considerable thickness of dark limestone and marl assigned to the Vraconian, overlain in turn by a series of red and yellow crumbly shale and marls with beds of limestone assigned to the Upper Cenomanian. The Albian fauna has much in common with that noted in the present collections. The Upper Cenomanian appears to have a number of species in common with the Turonian fauna listed below from the locality east of José Morales' house, and is very probably of the same age. It is worthy of note that some of the age assignments made in the literature dealing with South American geology are not well warranted by the fossils on which they are based. These fossils have received names originally applied to European and African species, and while the similarity is usually great, I doubt the validity of carrying most of the names so far afield and basing overpositive age assignments upon them. The confusion thus made possible is shown by Berry ⁸in discussing the fauna from a single bed near Huancavelica, Perú, where there occur together fossils previously assigned to European and African species of Aptian, Albian, Cenomanian, and Emscherian age.

The following lists give the species found in the various lots as designated by the accompanying labels:

1. Left bank of Río Napo, ¼ mile above the village of Napo at crest of anticline:

Inoceramus sp. indeterminable.

Cyprimeria n. sp. aff. *C. excavata* Morton (Pl. 10, Figs. 4-6).

Coelopoceras n. sp. A. aff. *C. lesseli* Brüggen and *C. springeri* Hyatt (Pl. 9, Figs. 1, 2).

Coelopoceras sp. undetermined.

1. Napo, near house of Señor Rivadeneyra:

Inoceramus labiatus Schlotheim.

Cyprimeria n. sp. aff. *C. excavata* Morton.

2. Left bank of Río Napo, 1 mile below village of Napo:

Inoceramus labiatus Schlotheim (Pl. 10, Fig. 1).

Roudairia intermedia Brüggen (Pl. 10, Figs. 2, 3).

The fauna above from localities on Río Napo is Turonian.

3. Río Misahuallí, 2 miles above confluence with Río Tena:

Oxytropidoceras (*Manuaniceras*?) *carbonarium* (Gabb) (= *Schloenbachia acutocarinata* Shumard of many authors). Middle Albian.

⁷ Schlagintweit Otto (1911) Die Fauna des Vracon and Cenoman in Perú. *Neues Jahrbuch*, Beilageb. 33, pp. 48, 65.

⁸ Berry E. W. and Singewald J. T. Jr. (1922) The Geology and Paleontology of the Huancavelica Mercury District. *Johns Hopkins University Studies in Geology*, No. 2, pp. 54-56.

4. Río Misahuallí, between mouth of Río Tena and Mouth of Río Hollín.*Exogyra* aff. *E. flabellata* D'Orbigny (Pl. 10, Fig. 12).*Pecten* sp. indeterminable.

Probably Turonian.

4. Río Misahuallí, below Tena.

Probably Turonian species.

Exogyra aff. *E. flabellata* D'Orbigny.*Pecten* (*Neithea*) *quinquecostata* Sowerby.

Middle Albian species.

Oxytropidoceras (*Manuaniceras*?) *carbonarium* (Gabb) (= *Schloenbachia acutocarinata* Shumard of many authors).**5. Trail to Río Jandachi, 1¼ miles east of José Morales' house, which is 4 miles north of Archidona on the Quito-Napo road:****Turonian species***Arca* n. sp. aff. *A. archiacana* D'Orbigny (Pl. 10, Fig. 13).*Glycimeris* n. sp. (Pl. 10, Fig. 14).*Pinna* sp. indeterminable (Pl. 10, Fig. 15).*Gervillia* sp. indeterminable (Pl. 10, Fig. 16).*Pteria* n. sp. aff. *P. gastrodes* Meek (Pl. 10, Figs. 17, 18).*Exogyra olisiponensis* Sharpe (Pl. 11, Figs 1-3).*Exogyra* aff. *E. flabellata* D'Orbigny (Pl. 11, Fig. 4).*Trigonia crenulata* var. *peruana* Paulcke (Pl. 11, Figs. 5, 6).*Trigonia* aff. *T. hondaana* Lea (Pl. 11, Fig. 7).*Pecten* (*Neithea*) *aequicostata* Lamarck (Pl. 11, Fig. 8).*Pecten* (*Syncyclonema*) n. sp. (Pl. 11, Fig. 9).*Plicatula* aff. *P. auressensis* Coquand (Pl. 11, Fig. 10).*Lima*? sp. indeterminable.*Modiola* aff. *M. socorrina* D'Orbigny (Pl. 11, Figs. 11, 12).*Modiola* n. sp. aff. *M. flichei* Peron (Pl. 11, Fig. 13).*Liopistha* n. sp. aff. *L. ligeriensis* D'Orbigny (Pl. 11, Figs. 14, 15).*Cardita* n. sp. aff. *C. subparallela* Gerhardt (Pl. 11, Figs. 16, 17).*Protocardia appressa* Gabb. (Pl. 11, Fig. 18).*Venus* n. sp. (Pl. 11, Figs. 19, 20).*Tellina*? sp. indeterminable (Pl. 11, Fig. 21).*Macra*? n. sp. (Pl. 12, Fig. 1).*Corbula* cf. *C. Peruana* Gabb (Pl. 12, Figs. 2, 3).*Gyrodes* n. sp. aff. *G. depressa* Meek (Pl. 12, Figs. 4, 5).*Turritella* aff. *T. vibrayeana* D'Orbigny (Pl. 12, Fig. 8).*Aporrhais* aff. *A. costae* Choffat (Pl. 12, Fig. 7).*Aporrhais* sp. indeterminable.*Fusus* n. sp. aff. *F. ubaquensis* Gerhardt (Pl. 12, Fig. 8).*Mammites* n. sp. (= *Mortoniceras cañaense* Gerhardt?) Pl. 12, Figs. 9-11).

6. Río Jandachi, 3 miles east of José Morales' house, which is 4 miles north of Archidona on Quito-Napo road:

Astarte sieversi Gerhardt

Exogyra aff. *E. flabellata* D'Orbigny (Pl. 10, Fig. 11).

Probably Turonian.

7. Five miles southeast of Archidona:

Middle Albian species

Inoceramus concentricus Parkinson (Pl. 12, Figs. 12, 13).

Ostrea sp. indeterminable.

Plicatula aff. *P. gurgitis* Pictet and Roux (Pl. 12, Fig. 14).

Brancoceras n. sp. (Pl. 12, Figs. 15-17).

Oxytropidoceras (*Manuaniceras*?) *carbonarium* (Gabb) (= *Schloenbachia acutocarinata* Shumard of many authors) (Pl. 12, Figs. 18-20).

Oxytropidoceras n. sp. aff. *O. belknapii* (Marcou) (Pl. 13, Figs. 1, 2).

Turonian species

Inoceramus labiatus Schlotheim.

Cyprimeria n. sp. aff. *C. excavata* Morton.

Exogyra olisiponensis Sharpe.

Coelopoceras n. sp. B. (Pl. 9, Figs. 3-5).

8. Ursuyacu Creek at crossing of Quito-Napo road, between abandoned house of Manuel Lara and the crossing of Río Jandachi. About 9½ miles north of Archidona:

Exogyra aff. *E. africana* Coquand (Pl. 13, Figs. 3, 4).

Pecten (*Neithea*) n. sp. aff. *P. phaseola* Lamarck (Pl. 13, Fig. 5).

Pecten n. sp. aff. *P. marrotianus* D'Orbigny (Pl. 13, Fig. 6).

Lima n. sp. (Pl. 13, Figs. 7, 8).

Plicatula aff. *P. gurgitis* Pictet and Roux (Pl. 13, Fig. 9).

This fauna appears to me to be Albian, though not conclusive as to age.

8. East of Andes between Río Napo and Cordillera Guacamayos:

Albian species

Inoceramus concentricus Parkinson (Pl. 13, Fig. 12).

Ostrea syphax Coquand (Pl. 13, Figs. 13, 14).

Lima n. sp. aff. *L. intermedia* D'Orbigny (Pl. 13, Figs. 10, 11).

Brancoceras n. sp. same as at locality 7.

Oxytropidoceras (*Manuaniceras*?) *carbonarium* (Gabb) (= *Schloenbachia acutocarinata* Shumard of many authors).

Turonian species

Inoceramus labiatus Schlotheim (Pl. 10, Fig. 7).

Inoceramus sp. indeterminable (Pl. 10, Fig. 8).

Pecten quinquecostata Sowerby (Pl. 10, Figs. 9, 10).

Unassigned species

Pholadomya? sp. indeterminable.

Venerid pelecypod, indeterminable.

Gastropod, indeterminable.

Red beds and conglomerates

Overlying the Napo limestone are red beds and conglomerates which extend in a belt from north to south across the area explored. A contact between the Napo limestone and the red beds is well exposed at Venecia, 7 miles east of Napo. Although the bedding appears conformable, the abrupt change from hard, fossiliferous limestone to soft, red sandstones and shales is very marked and may represent an unconformity of some magnitude. No fossils were found in the red shales. The dip is eastward at angles of 6°-10°. Eastward from Venecia the river clays and sands cover these beds in a short distance. West of Napo glimpses of the red beds are seen on the west limb of the Napo anticline. They are here obscured by the overlying volcanic agglomerate. In the vicinity of Tena and Archidona remnants of the red clays are found on the west side of the Napo structure. The thickness of red beds exposed is not great, being about 1200 feet at Venecia, but the overlapping alluvium probably obscures a much thicker section. South of Napo, near the headwaters of the Río Arajuno and Río Curaray, the red beds grade upward into cross-bedded sandstones and conglomerates which carry lignitic wood and cannon-ball concretions. What appears to be the contact of the conglomerates with the red clays was observed on the Río Anzu, 4 miles south of Napo. These conglomerates may represent local phases of the red beds, and for the purposes of this report will be grouped with them, as no fossils were found which would indicate their age.

West of the belt of outcrop the red beds are overlain by volcanic material, and to the east they are covered by alluvium. The age of these red beds is one of the unsolved problems of this region. They are tentatively grouped as Tertiary.

James Orton⁹ made no direct reference to red beds close to the village of Napo, but did mention clay deposits interstratified with lignites which he found at the mouth of the Curaray and at Pebas, 300 miles farther east. Orton referred to his Pebas beds (map, Fig. 1) as of not later than Pliocene age, but it is doubtful whether they can be correlated with the sandstones and conglomerates of the Napo region on the strength of lignitic layers alone.

Red beds of Oligocene age have been identified east of the Andes in Perú. A fragment of a jawbone with well-preserved teeth from the salt gypsum beds which lie above the limestones was found by J. G. Richards at Chiococa, near Chepeza, on Río Huallaga, Perú, which, is 250 miles south of Napo¹⁰. This was examined by H. E. Anthony¹¹. He describes the fossil teeth as those of a tapiroid animal which lived in Oligocene time.

⁹ James Orton, *The Andes and the Amazon* (New York: Harper Brothers, 1870), p. 282. "We came down the Napo and Marañón, and stopped at this place [Pebas]. Here we discovered a fossiliferous bed intercalated between the variegated clays so peculiar to the Amazon. It was crowded with marine Tertiary shells! . . . It was unmistakable proof that the formation was not drift but Tertiary: not of fresh but of salt water origin".

"The species as determined by W. M. Gabb, Esq., of Philadelphia, are: *Neritina pupa*, *Turbonilla minuscula*, *Mesalia orloni*, *Tellina amazonensis*, *Pachydon oblique* and *P. tunua*. All of these are new forms, excepting the first, and the last is a new genus. It is a singular fact that the *Neritina* is now living in the West India waters, and the species found at Pebas retains its peculiar markings ... Interstratified with the clay deposits are seams of highly bituminous lignite; we traced it from the mouth of the Curaray on the Río Napo to Loreto on the Marañón, a distance of about 400 miles. It occurs also at Iquitos".

¹⁰ Richards J. G. (1920) Expedition on the Amazon for the Pure Oil Co.

¹¹ Anthony H. E. (1924) A New Fossil perissodactyl from Perú. *American Museum Novitates*. No. III, Op. 21. New York: American Museum of Natural History.

Volcanic agglomerate

Beds of volcanic *débris* overlie the Napo rocks, in many places obscuring all exposures. This is particularly true in the belt close to the base of the Andes. These volcanic beds are made up of poorly assorted, angular, volcanic fragments among which are round lapillae and bombs.

Mud flows and landslides frequently occur in these beds. The western half of the area explored, particularly the portion east of the volcano Sangay, is covered with these volcanic agglomerates which in age probably range from late Tertiary to Recent.

STRUCTURE

The great fault which forms the east scarp of the Andes is the major structural feature of this region. Its throw can be roughly estimated by comparing the Cretaceous rocks reported in the mountains at elevations of 10000 feet or more with those at Napo, which are at an elevation of 2000 feet. The fault zone is obscured by extrusive volcanic material. The regional dip of the sedimentary rocks in the Oriental region is eastward away from the mountains. Near the mountains the beds dip westward into the fault. This reversal of dip gives rise to anticlinal structures which lie parallel to the mountains.

The Napo anticline

The axis of the Napo anticline lies just west of the town of Napo. The reversal of dip is well shown in black shales and limestones which are exposed along the river. The west dip is 6° - 10° , the east dip about the same. The axis of this anticline strikes $N45^{\circ}E.$, passing east of Tena and crossing the Río Misahuallí just east of the mouth of the Río Hollín. Farther northeast it probably becomes a part of the Galeras mountain uplift, which was not explored. The plunge of the Napo anticline to the southwest is shown by the existence of the Hollín sandstone on the surface near the mouth of the Río Hollín, while along the Río Napo it is overlain by several hundred feet of limestone and shale. The axis of the Napo anticline projected southwestward follows the valley of the Río Anzu. This valley is probably anticlinal throughout its length.

Mirador uplift

In the Mirador hills northeast of Mera and near the headwaters of the Río Anzu a mass of dark gray limestone resembling the Napo beds and lying at elevations above 4000 feet suggests an uplift in this area. These beds appear to be nearly horizontal. A sink-hole type of topography has developed on the limestone outcrops. Fossils collected were thrown away by the Indian carriers when they discovered their pack baskets contained rocks. Remnants of red beds capping some of the hills indicate that these limestones are equivalent to those west of Venecia on the Río Napo.

Faulting north of Canelos

A zone of faulting extends from the headwaters of the Río Curaray nearly to Canelos, a distance of 30 miles. The best evidence was found in the high ridge between the Río Curaray and the Río Villano. The downthrow side is to the east. Beds of lignitic conglomerate are faulted against the red beds. The amount of displacement could not be determined accurately. Some local exposures showed a throw of 150 feet. This fault zone is 25 miles east of the Mirador uplift and may be the eastern escarpment of the high land which extends eastward from the Mirador.

Syncline along the Río Arajuno

Where the trail from Napo to Canelos crosses the Río Arajuno there is a syncline in the red beds. It was not followed for any distance, but its position seems to indicate that it follows the course of the Río Arajuno which flows into the Napo about 10 miles below Venecia. This syncline, with an axis roughly parallel to the Napo anticline, suggests the existence of another anticline southeast of the Napo between that river and the Río Curaray in an area which was not explored.

EAST OF ALAPICOS

Rock specimens brought from the confluence of the Río Palora and Río Pastaza by the Indians resembled the petroliferous limestones at Napo, but the high water in the Río Palora prevented a visit to those outcrops. They are mentioned as being from a possible uplift similar to that at Napo and Mirador, where the underlying limestones have been exposed by the erosion of the red beds.

EVIDENCE OF PETROLEUM

The Napo limestone is found to be more or less petroliferous. Along the Río Napo the limestones and black shales are in many places impregnated with asphaltic oil. Small quantities of black oil seep from cavities and bedding planes of the upper Napo limestone east of El Molino de Latas. On the axis of the Napo anticline just west of the settlement of Napo gas escapes from the black shales and can be observed at low water on the north side of the stream. Petroliferous limestones occur in the Mirador uplift and in the area east of Alapicos.

The Hollín sandstone also carries asphaltic material. On the Río Misahuallí near the mouth of the Río Hollín there are seepages of asphaltic oil from the Hollín sandstone which outcrops on the axis of the Napo anticline. These seepages are from the lower half of the sandstone. The seepage oil occurs with sulphur water and forms pools 10-15 feet across. There is some evidence of natural gas. The upper beds of the Hollín sandstone exposed along the Río Misahuallí are stained with asphaltic oil. East of Archidona the Río Hollín and its tributary, the Río Jandachi, cut across the west limb of the Napo anticline and have exposed the Hollín sandstone in their canyon walls. Seepages occur from the oil-saturated sandstone, but the nearly vertical walls have prevented any great accumulation. This oil-bearing sandstone extends for several miles. Its northern limits were not determined.

COMPARISON WITH OTHER AREAS

The oil-bearing beds at Napo may be compared to the Colón shales and limestones of Upper Cretaceous age which occur along the west side of the Maracaibo Basin in Venezuela, 700 miles to the northward. Liddle¹² has measured sections showing a thickness of 3500 feet of Colón shale overlying 1000 feet of the upper part of the Lower Cretaceous which lies upon a basal Cretaceous conglomerate. The Colón shales are petroliferous and contain fossils similar to those of the Napo limestone. Along the west side of the Maracaibo Basin several large seepages occur from the upturned Colón beds.

In Colombia Anderson¹³ has described the Villeta and Guadalupe beds of Middle to Upper Cretaceous age. Their thickness is similar to that measured on the Venezuelan side of the mountains. In the upper Magdalena Valley Garner¹⁴ has referred to the thick bituminous shales in the Upper Cretaceous as being the probable source of much of the oil found there.

Joseph T. Singewald Jr., recently announced the results of his observations on the Pongo de Manseriche on the upper course of the Amazon of eastern Perú¹⁵. He found a thick sandstone overlain by a Cretaceous shale and limestone series, above which are the red beds. This sequence agrees closely with that found in the Napo section, although his thicknesses are considerably greater.

Seepages extending 600 kilometers southward from the Province of Mendoza, Argentina, were found by Robert Anderson¹⁶ to be from beds of Jurassic and Lower Cretaceous age. They contain many marine fossils and are thought to be the source beds for the seepage oil.

ORIGIN OF THE OIL

The oil found in this area probably has its origin in the Napo limestone, which consists of highly fossiliferous marine limestones and shales of Cretaceous age found to be petroliferous wherever exposed. This oil in the upper beds of the Hollín sandstone may have migrated laterally from the Napo limestone, which is adjacent to it along the flanks of the Napo anticline. Seepages from the base of the Hollín sandstone suggest upward migration from organic beds not exposed.

Igneous intrusions may have played some part in the migration and accumulation of oil in other parts of the region, but in the Napo area, where the best evidences of oil were observed, intrusions have not been found. The oil-bearing rocks are relatively close to the eastern scarp of the Andes and are associated with volcanic flows, but have not suffered any great alteration.

¹² Liddle R. A. (1928) The Geology of Venezuela and Trinidad.

¹³ Anderson F. M. (1926) Original Source of Oil in Colombia. *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 4. April, 1926.

¹⁴ Garner A. H. (1927) General Oil Geology of Colombia. *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 2. February, 1927, p. 153.

¹⁵ Singewald J. T. Jr. (1926) The Pongo de Manseriche, Perú. Paper presented before the Geological Society of America, Madison, Wisconsin. December, 1926

¹⁶ Anderson Robert (1926) Observations on the Occurrence and Origin of Petroleum in Argentina and Bolivia. *Bulletin Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 9. September, 1926, p. 857.

PROSPECTS FOR OIL FIELDS

Geological work has been of a *reconnaissance* nature, all observations being limited to the vicinity of streams or along trails cut through the forest.

The evidence of petroleum found in the rocks of the Napo section leads to the conclusion that the Hollín sandstone has possibilities of production wherever proper depth and structural conditions exist.

Sandstones and shales in the lower part of the red beds may act as reservoirs for oil by migration upward from the uppermost Napo beds. Tertiary beds higher than those observed may also be oil-bearing under structures east of the Napo area.

The Río Napo oil-bearing Cretaceous beds lying close to the eastern base of the Andes of Ecuador are another link in the chain of oil-bearing Cretaceous strata extending from Venezuela and Colombia to Argentina.

DISCUSSION

Joseph T. Singewald Jr.: The Permian area south of Ecuador shows the same stratigraphic units as Ecuador. It differs in absence of volcanics and greater thickness of beds. The Hollín sandstone probably is the same as the coal-bearing quartzitic sandstone of the main Andes, which is lowermost Cretaceous or uppermost Jurassic. The Napo limestone-shale ranges from Albian to Coniacian in age. The red beds in Perú lie conformably on the Napo series, hence must be in part uppermost Cretaceous and may extend into the Tertiary. Overlying the red beds is a younger series of beds of considerable thickness. All of these strata participated in the orogenic movements of the eastern Andes. In the Amazon Basin are flat-lying beds with a Pliocene brackish-water fauna, long known from collections made by Orton and other early explorers at the town of Pebas. The folding of the eastern Andes occurred probably in Miocene time. The red beds in Perú are sparingly fossiliferous, containing poorly preserved gastropods and a few pelecypods.

PLATES**Plate 9**

Figure	Description
1, 2	<i>Coelopoceras</i> n. sp. A. aff. <i>C. lesseli</i> Brügger and <i>C. springeri</i> Hyatt. Side view and cross-section of an internal cast from left bank of Río Napo, ½ mile above the village of Napo at crest of anticline.
3-5	<i>Coelopoceras</i> n. sp. B from Río Hollín, 5 miles southeast of Archidona. Figures 3, 4: Side view and cross-section of an internal cast. Figure 5: Side view of another specimen retaining the shell.

All figures reduced one-seventh.

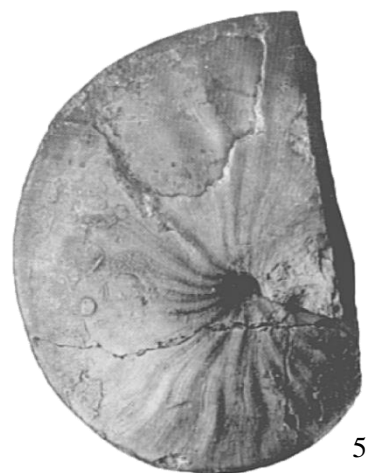
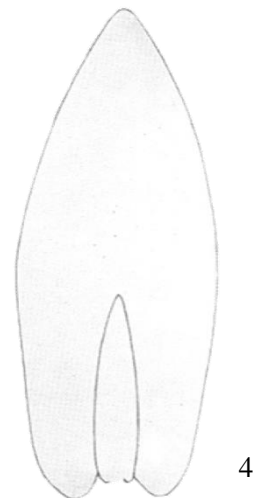
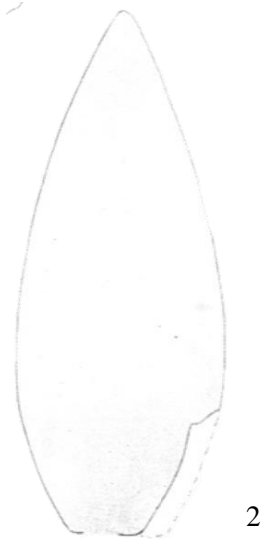


Plate 10

Turonian Fossils from Eastern Ecuador

Figure	Description
1	<i>Inoceramus labiatus</i> Schlotheim. Side view of specimen flattened in shale, from Río Napo, just below village of Napo.
2, 3	<i>Roudairia intermedia</i> Brügger. Side and front views of specimen from left bank of Río Napo, 1 mile below village of Napo.
4, 6	<i>Cyprimeria</i> n. sp. aff. <i>C. excavata</i> Morton, from left bank of Río Napo, ½ mile below village of Napo. Figures 4, 5: Side and cardinal view of a specimen. Figure 6: Cross-section of hinge of another specimen.
7	<i>Inoceramus labiatus</i> Schlotheim. Side view of specimen flattened in shale from region between Río Napo and Cordillera Guacamayos.
8	<i>Inoceramus</i> sp. Side view of specimen from region between Río Napo and Cordillera Guacamayos.
9, 10	<i>Pecten</i> (<i>Neithea</i>) <i>quinquecostatus</i> Sowerby from region between Río Napo and Cordillera Guacamayos. Figure 9: View of right valve. Figure 10: View of left valve.
11	<i>Exogyra</i> aff. <i>E. flabellata</i> D'Orbigny. Side view of left valve from Río Jandachi, 3 miles northeast of José Morales' house, which is on Quito-Napo road 4 miles north of Archidona.
12	<i>Exogyra</i> aff. <i>E. flabellata</i> D'Orbigny. Side view of left valve from Río Misahuallí between mouth of Río Tena and mouth of Río Hollín.
13	<i>Arca</i> n. sp. aff. <i>A. archiacana</i> D'Orbigny. Side view of internal cast from locality 1¼ miles east of house of José Morales, on trail leading east to Río Jandachi. Morales' house is 4 miles north of Archidona on Quito-Napo road.
14	<i>Glycimeris</i> n. sp. side view of internal cast from same locality as last.
15	<i>Pinna</i> sp. Side view of internal cast from same locality as last.
16	<i>Gervillia</i> sp. Side view of internal cast from same locality as last.
17, 18	<i>Pteria</i> n. sp. aff. <i>P. gastroides</i> Meek, from same locality as last. Figure 17: Side view of an internal cast of a right valve. Figure 18: Side view of an internal cast of a left valve.

All figures reduced one-seventh.

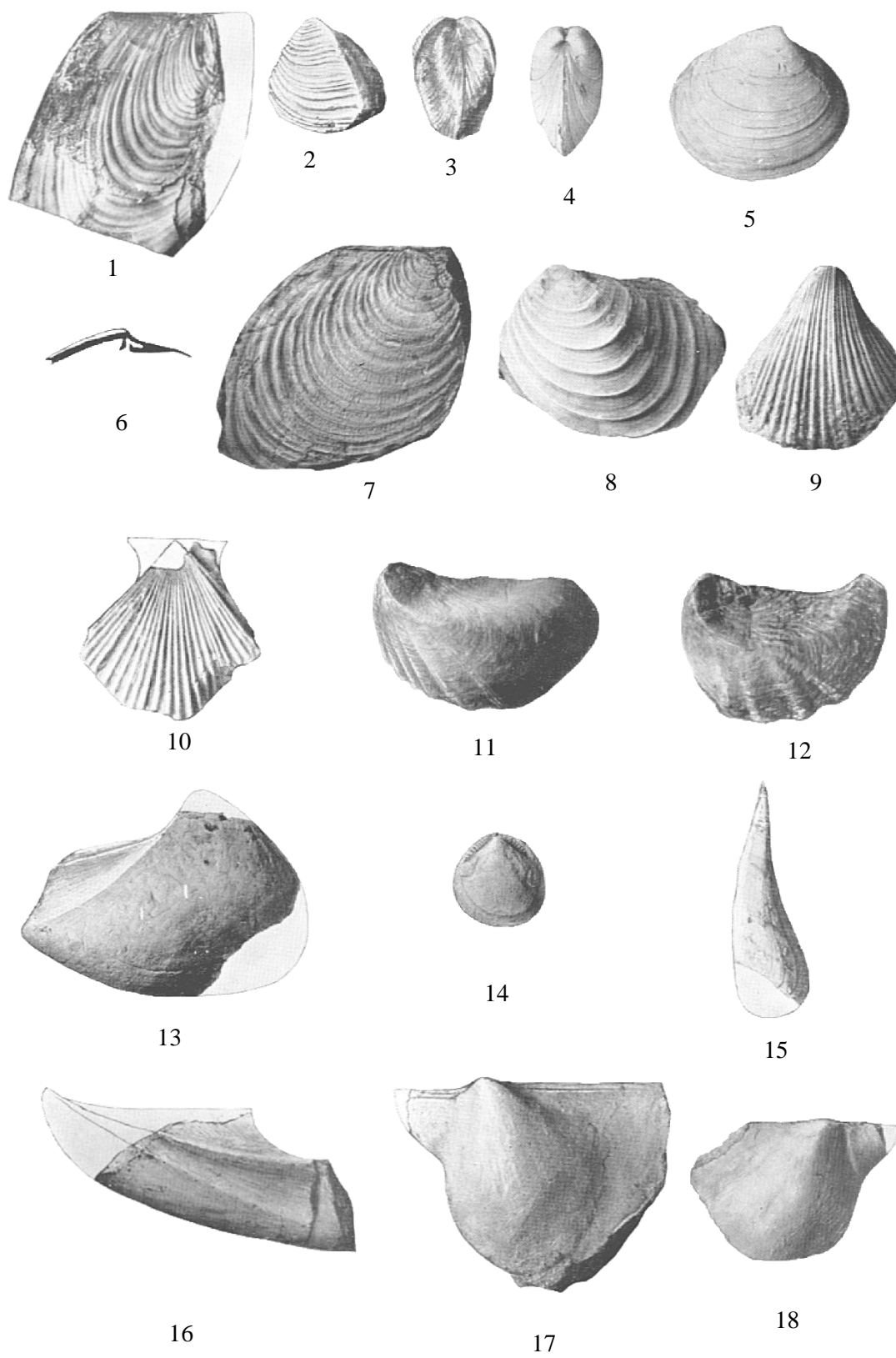


Plate 11

Turonian Fossils from Eastern Ecuador

All specimens shown on this plate are from locality 1¼ miles east of José Morales' house on trail leading east to Río Jandachi. Morales' house is 4 miles north of Archidona.

Figure	Description
1-3	<i>Exogyra olisiponensis</i> Sharpe. Figures 1, 2: Top and side views of natural mold of interior of large (left) valve. Figure 3: View of plaster cast from natural mold of exterior of small (right) valve, somewhat enlarged.
4	<i>Exogyra</i> aff. <i>E. flabellata</i> D'Orbigny Side view of internal cast of left valve.
5-6	<i>Trigonia crenulata</i> var. <i>peruana</i> Paulcke. Side and cardinal views of internal cast.
7	<i>Trigonia</i> aff. <i>T. hondaana</i> Lea. Side view of internal cast.
8	<i>Pecten</i> (<i>Neithea</i>) <i>aequicostatus</i> Lamarck. Side view of internal cast.
9	<i>Pecten</i> (<i>Syncydonema</i>) n. sp. Side view of internal cast of part of valve.
10	<i>Plicatula</i> aff. <i>P. auressensis</i> Coquand. View of squeeze from mold of surface of part of valve.
11-12	<i>Modiola</i> aff. <i>M. socorrina</i> D'Orbigny. Figure 12: View of squeeze from mold of exterior of left valve. Figure 11: View of internal cast of right valve.
13	<i>Modiola</i> n. sp. aff. <i>M. flichei</i> Peron. Side view of internal cast.
14-15	<i>Liopistha</i> n. sp. aff. <i>L. ligeriensis</i> D'Orbigny. Side and cardinal views of internal cast of nearly complete shell
16-17	<i>Cardita</i> n. sp. aff. <i>C subparallela</i> Gerhardt. Side and front views of internal cast.
18	<i>Protocardia appressa</i> Gabb. Side view of internal cast.
19-20	<i>Venus</i> n. sp. Figure 19: Side view of internal cast of right valve. Figure 20: View (×4) of squeeze of hinge.
21	<i>Tellina?</i> sp. indeterminable. Side view of internal cast.

All figures except figure 20 reduced one-seventh

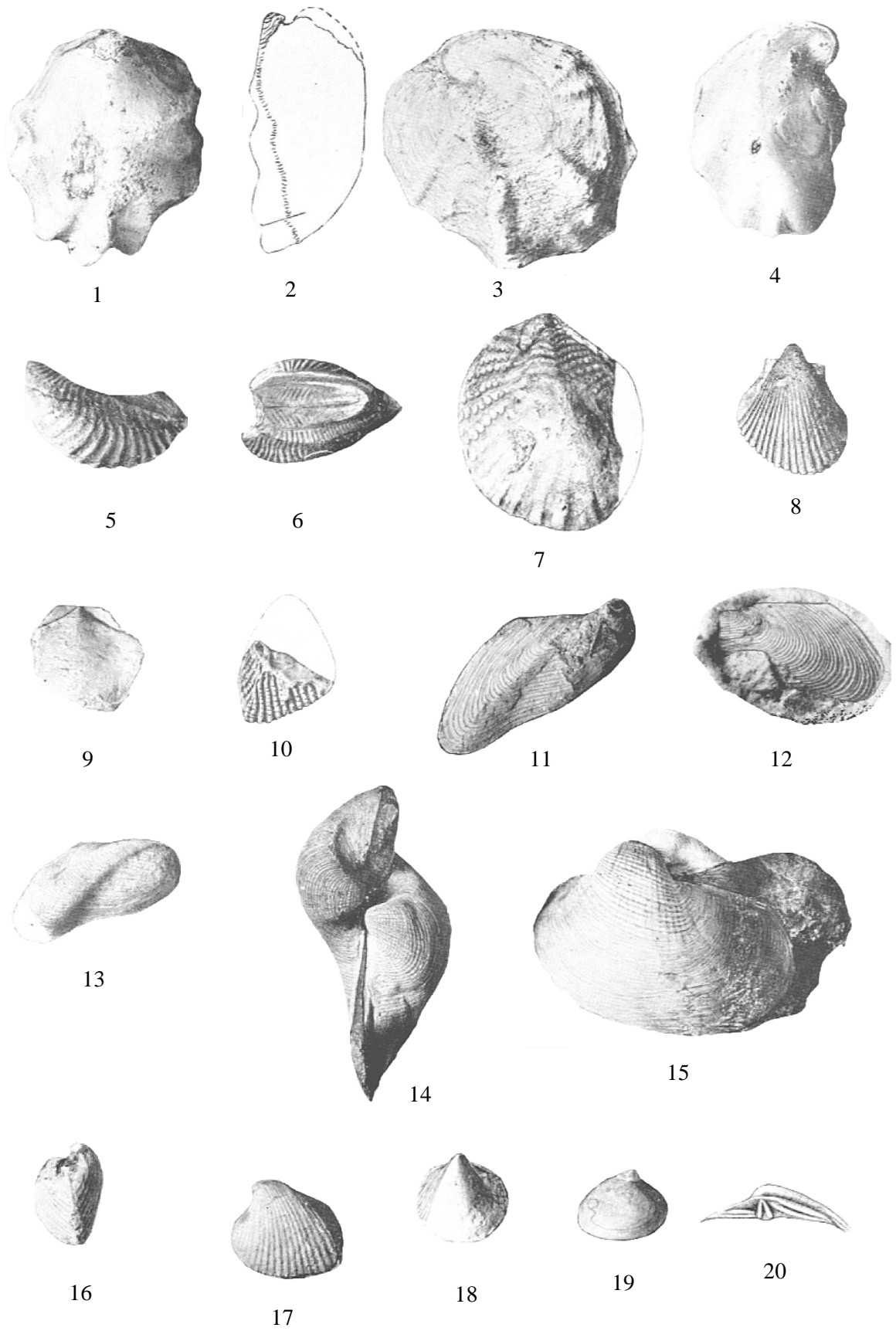


Plate 12

Turonian and Albian Fossils from Eastern Ecuador

Figure	Description
Turonian Fossils	
1	<i>Mactra?</i> n. sp. Side view of internal cast from locality 1¼ miles east of José Morales' house, on trail leading east to Río Jandachi. Morales' house is 4 miles north of Archidona.
2-3	<i>Corbula</i> aff. <i>C. peruana</i> Gabb, Side and cardinal views of an internal cast from same locality as last.
4-5	<i>Gyrodes</i> n. sp. aff. <i>G. depressa</i> Meek. Two views of an internal cast from same locality as last.
6	<i>Turritella</i> aff. <i>T. vibrayeana</i> D'Orbigny. View (×2) of fragment from same locality as last.
7	<i>Aporrhais</i> aff. <i>A. costae</i> Choffat. View of internal cast from same locality as last.
8	" <i>Fusus</i> " n. sp. aff. <i>F. ubaquensis</i> Gerhardt. View of an internal cast from same locality as last.
9-11	<i>Mammites</i> n. sp. (= <i>Mortoniceras cañaense</i> Gerhardt?). Same locality as last. Figures 9, 10: Side and back view of internal cast. Figure 11: View of plaster cast from mold of exterior of same specimen.
Albian Fossils	
12-13	<i>Inoceramus concentricus</i> Parkinson. Side and front views of an internal cast from Río Hollín, 5 miles southeast of Archidona.
14	<i>Plicatula</i> aff. <i>P. gurgitis</i> Pictet and Roux. View of an internal cast from same locality as last.
15-17	<i>Brancoeras</i> n. sp. From same locality as last. Figures 16, 17: Side and siphonal views of internal cast. Figure 15: Suture of another specimen.
18-20	<i>Oxytropidoceras</i> (<i>Manuaniceras?</i>) <i>carbonarium</i> (Gabb) (= <i>Schloenbachia acutocarinata</i> Shumard of many authors). Side and siphonal views and suture (×2) of specimen from same locality as last.

All figures except figures 6 and 18 reduced one-seventh.

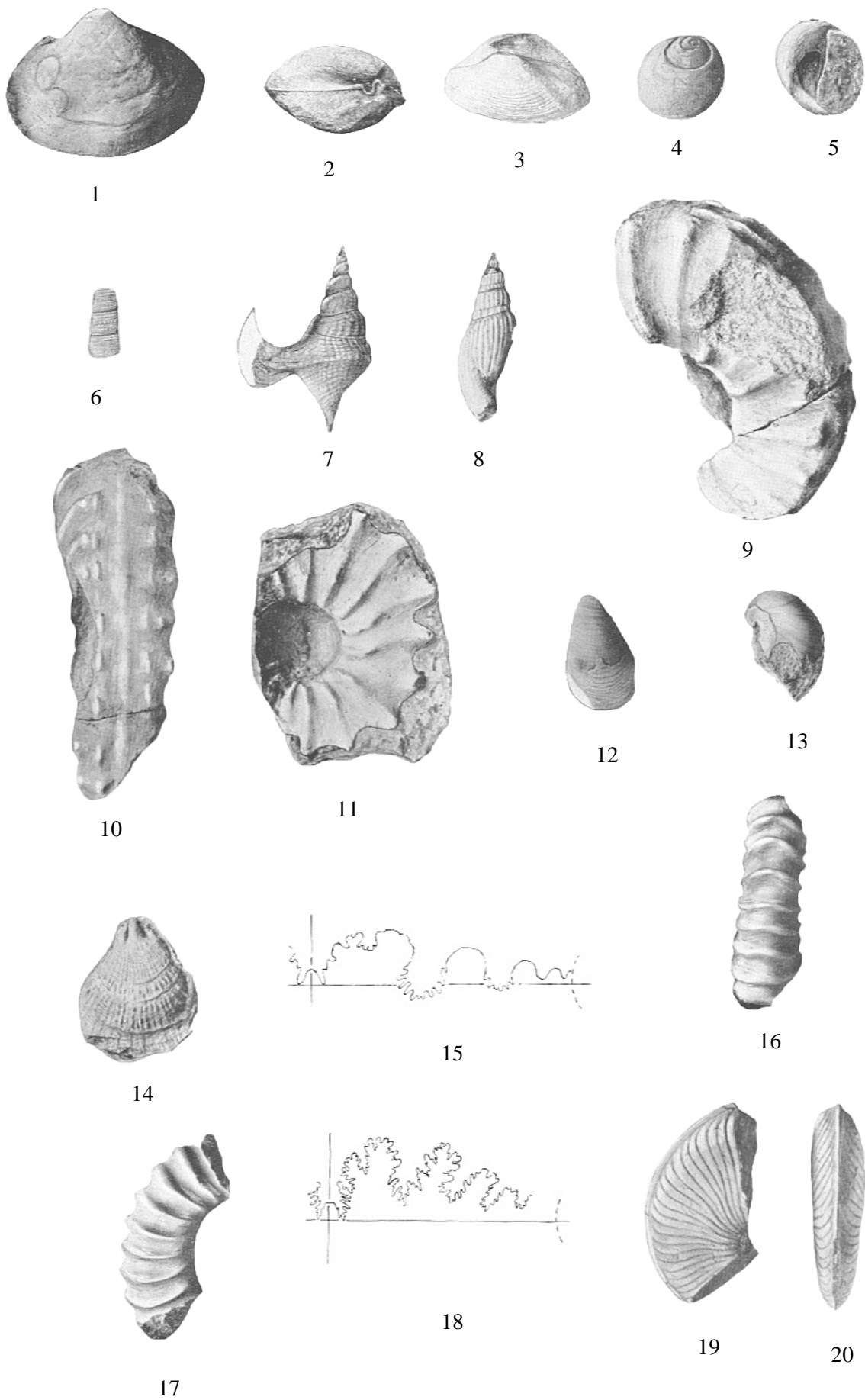


Plate 13

Figure	Description
Albian Fossils from Eastern Ecuador	
1-2	<i>Oxytropidoceras</i> n. sp. all. <i>O. belknapi</i> (Marcou). Side view and cross-section of only specimen, an internal cast retaining fragments of the shell, from Río Hollín, 5 miles southeast of Archidona.
Probably Albian Fossils	
3-4	<i>Exogyra</i> aff. <i>E. africana</i> Coquand, Side and front views of an internal cast from Ursuyacu at crossing of Quito-Napo road, about 9½ miles north of Archidona.
5	<i>Pecten</i> (<i>Neithea</i>) n. sp. aff. <i>P. phaseola</i> Lamarck. View of only specimen, from same locality as last.
6	<i>Pecten</i> n. sp. aff. <i>P. marrotianus</i> D'Orbigny. View of only specimen, from same locality as last.
7-8	<i>Lima</i> n. sp. View of only specimen and part of surface (×4) from same locality as last.
9	<i>Plicatula</i> aff. <i>P. gurgitis</i> Pictet and Roux. View of a specimen from same locality as last.
10-11	<i>Lima</i> n. sp. aff. <i>L. intermedia</i> D'Orbigny. View of only specimen and part of surface (×4) from region between Río Napo and Cordillera Guacamayos.
12	<i>Inoceramus concentricus</i> Parkinson. Side view of an internal cast from region between Río Napo and Cordillera Guacamayos.
13-14	<i>Ostrea syphax</i> Coquand. Side and front views of specimen from region between Río Napo and Cordillera Guacamayos.

All figures except figures 8 and 11 reduced one-seventh.



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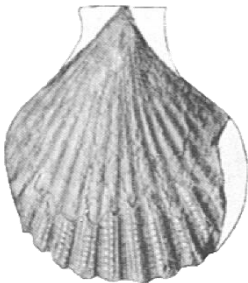
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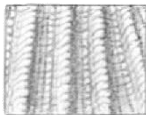
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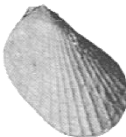
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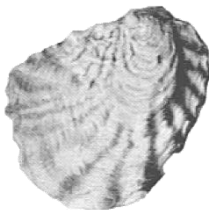
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**THE LAVAS OF THE VOLCANO SUMACO,
EASTERN ECUADOR,
SOUTH AMERICA**

by

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and

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INTRODUCTION

In February, 1541, Gonzalo Pizarro, the brother of the famous conqueror of Perú, left Quito at the head of an expedition whose object was to conquer and explore the “land of cinnamon”, a region reported to be situated at the east base of the Andes Mountains, and to be rich beyond belief not only in cinnamon, but in gold and other precious metals. The expedition ended in a disastrous return to Quito after many months of fruitless wandering in the rainy jungles of the headwaters of the Amazon River. It was not, however, a complete failure for Francisco Orellana, one of Pizarro’s captains, becoming detached with a few companions from the main party in December, 1541, descended for the first time the Río Napo to the Amazon and then the main stream to the Atlantic, thus accomplishing one of the great geographic feats of the sixteenth century.

According to historians¹ the members of the expedition of Pizarro made no stop of any length after leaving Quito till they came to a “Provincia” called “Zumaco, which is on the slopes of a high volcano”; here they stayed two months and in the record of their journey¹ is the first historical mention of the volcano Sumaco.

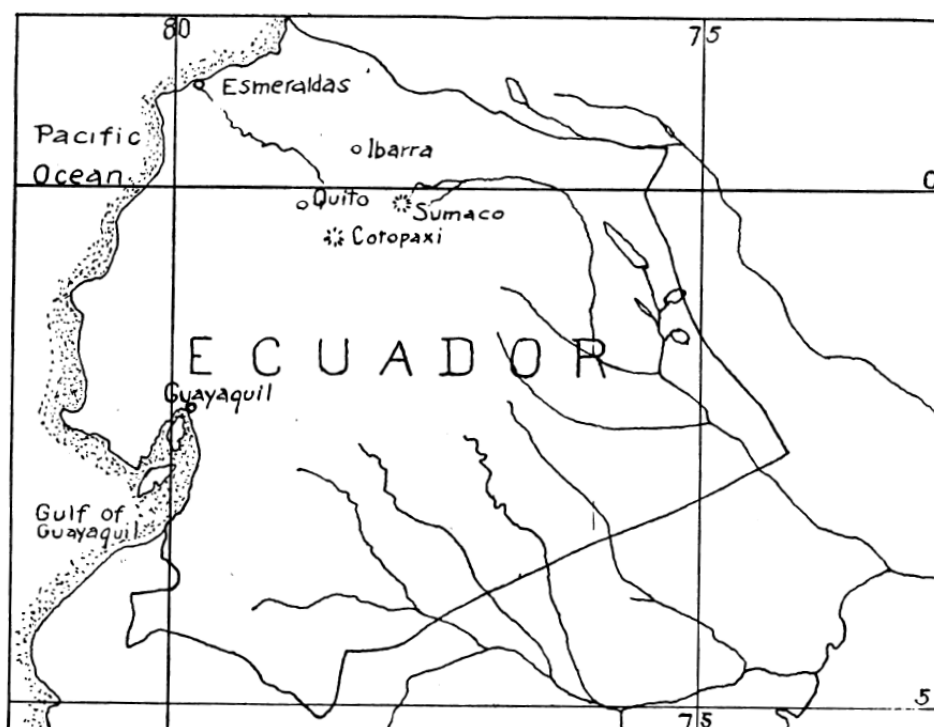


Fig 1. Sketch map of Ecuador showing approximate location of Sumaco volcano (see at the end the updated map)

¹ López de Gomara, Francisco, *Primera y Segunda Parte de la Historia General de las Indias*. Zaragoza, 1552. Chapter 143 of the “Primera Parte”
Zarata, Augustin de, *Historia del Descubrimiento y Conquista del Perú*. Antwerp, 1555. Book. 4, chapter 2.

Statements regarding the volcano and its location have since then appeared from time to time² and Jiménez de la Espada describes the crater of the volcano as having a diameter of 100 meters. Some of the early explorers have mapped the volcano, but in no case is it correctly located on their maps³, nor do Theodor Wolf (1892), Vacas Galindo or Fleming (1912) show it on their maps of Ecuador.

The geologists Joseph H. Sinclair and Theron Wasson, while descending the Río Napo in 1921, and using Wolf's map of Ecuador, were naturally considerably surprised, when on September 9, 1921, at a point forty-four miles below the village of Napo, they noted thirty-one miles to the northwest a lofty, cone shaped and isolated peak, rising high above the Amazon forests. From the traverse of the Río Napo between Napo and the mouth of the Río Coca, and from a traverse from Napo north through Tena and Archidona to the base of the Guacamayos Range, the exact position of the volcano was found by intersections and its elevation by vertical angles, to be 0°32' south latitude, 77° 38' west of Greenwich, and its highest point 12670 feet above the sea⁴. The location is shown approximately on the accompanying sketch map, Fig. 1. In 1925 Commander George M. Dyott, while descending the Río Napo, visited this mountain⁵ (Fig. 2).

On comparing the accounts of Jiménez de la Espada and Dyott, it seems probable that a period of volcanic activity occurred between 1865 and 1925, for Jiménez de la Espada describes the crater as being over 328 feet wide, while Dyott gives it a diameter of about 900 feet; and while the former describes a great opening in the crater to the south, Commander Dyott states that the crater is perfectly formed. Unfortunately, we have no comparative data on the depth of the crater.

² Ordoñez de Cevallos, Pedro, *Viaje del Mundo*, Madrid. 1614.

Jiménez de la Espada, Marcos, *Primeros Descubrimientos del País de la Canela*, El Centenario, Madrid, 3, 437-457, 1892.

Rice, Alexander Hamilton, *From Quito to the Amazon via the Río Napo*, *The Geog. Jour.*, 21, 401-408, 1903.

³ Maldonado, Pedro, *Carta de la Provincia de Quito*, 1750.

Díaz de la Fuente, Appolinario, *Mapa Geográfico de la Provincia de Quixos*, 1777.

Humboldt, Alexander, *Atlas Géographique et physique des régions équinoxiales du nouveau continent*, Paris, 1814-1834, Plate XI.

Villavicencio, Manuel, *Carta Corográfica de la República del Ecuador*, New York, 1858

⁴ Sinclair, J.H., and Wasson, T., *Explorations in Eastern Ecuador*, *The Geog. Review*, 13. 190-210, 1923

⁵ Dyott, G. M., *On the Trail of the Unknown in the Wilds of Ecuador and the Amazon*, New York, 1926

THE LAVAS OF SUMACO

Commander Dyott collected specimens at our request from Sumaco and thin sections were made of these. The petrographic examination of these thin sections has revealed that the magma of the volcano Sumaco is distinguished by the presence of feldspathoid minerals.

The fact that the lavas of the volcanoes of Ecuador have been subjected of a great deal of petrographic study indicates that the Sumaco magma is unique in Ecuador, for these minerals could not have been overlooked in the numerous specimens of rock examined, especially by German petrographers, from the volcanoes Cotopaxi, Pichincha, Tungurahua, etc.



Fig 2. Photograph of volcano Sumaco, taken in 1925 by Commander Georg M. Dyott from the pueblo of San José, Eastern Ecuador

According to Iddings⁶ the lavas of Ecuador are chiefly andesites, grading into basalts in some instances; in certain localities dacites and rhyolites are common, but Iddings does not mention the occurrence of any feldspathoid-bearing lavas, nor is any reference made to such lavas in the literature descriptive of the petrography of Ecuador rocks. Nephelite syenites are more or less common in Brazil, and they are mentioned as occurring in French Guiana and Patagonia. On the eastern flanks of the Andean ranges in Argentina and Patagonia nephelite-bearing lavas are associated with the usual Andean volcanics, and phonolites, nephelite-basalts, leucite-basalts and tephritic basalts occur in Brazil⁷.

⁶ Iddings, J. P., *Igneous Rocks*, Vol. II, p. 441.

⁷ Described in various papers by O. A. Derby, F. Graeff, E. Hussak, J. Machado, Hunter and H. Rosenbusch, E. O. Hovey, F. E. Wright, References cited by J. P. Iddings, *Igneous Rocks*, Vol. II, p. 486

The volcano of Sumaco differs from all other volcanic peaks of Ecuador in that it is isolated from the main range of the Andes, that it rises from a comparatively low elevation on the Amazon plain, and that it carries on its flanks uptilted sediments through which it has broken. From the description of the general geology of the region by Sinclair and Wasson ⁸it is clear that the volcano was born at a date subsequent to the deposition of the late Cretaceous strata around its base. Its uneroded condition indicates that it is of recent origin and the comparison above made of descriptions of the condition of the crater in 1865 and 1925 point to the possibility of activity between those dates.

Because this is the first petrographic description of any rocks from this volcano, which is the first volcanic center known east of the Andes in Ecuador, the following descriptions of the specimens collected by Commander Dyott are offered in detail. The observations are based on a petrographic study of nine thin sections cut from the specimens collected by Commander Dyott from the flanks of the volcano and from the rim of the crater, and on analyses of four of the lavas; the specimens collected were very small so that but little was left of each sample after the thin sections were cut. With the exception of No. 6, which is a foraminiferal limestone, all the rocks are andesitic and basaltic lavas, the striking thin is the presence of feldspathoids in all but one of the lavas. In this respect they differ from the usual Andean volcanics of Ecuador, since no feldspathoid-bearing lavas have been found in Ecuador, so far as the writers know. While in a general way all the specimens of the lavas are similar, there is sufficient difference between them to warrant individual descriptions, more especially since rocks of this character have never before been found in this locality.

Petrographic description

- *Specimen No. 1*, from the rim of the crater on the summit of Sumaco, is a moderately strongly porphyritic tephrite carrying phenocrysts of plagioclase feldspar ranging from andesine to labradorite in composition, which exhibit a striking zonal development, complex twinning and which contain zonally distributed inclusions. Pale green, very slightly pleochroic phenocrysts of augite are as plentifully distributed as are the plagioclase phenocrysts. The augite crystals are occasionally twinned; a few of them show the "hour-glass" structure and zonal development as well. In those sections showing the most marked pleochroism the color changes range from pale green to shades of yellowish green. Olivine is so very sparingly distributed that only one crystal was seen, associated with augite that occurs as a rim or border around it. The rock carries considerable magnetite in large and small grains, and a little accessory apatite that is strongly colored brown by what is judged to be finely disseminated magnetite dust.

⁸ Manuscript in the hands of the editor of the Bulletin of the American Association of Petroleum Geologists.

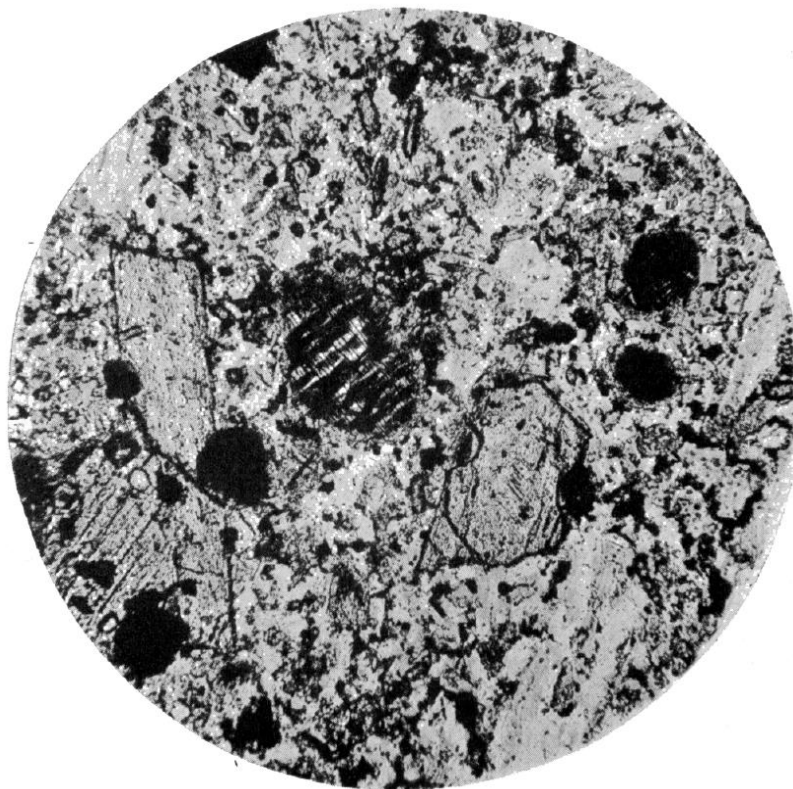


Fig. 3. *Photomicrograph of Specimen No. 1. Ordinary Light, $\times 54$. Showing one of the h  ynite crystals, with cleavage, filled with fine, dark included matter. The character of the groundmass is shown a little more clearly at this higher magnification and the augite phenocrysts together with the clear plagioclase crystals may be readily seen.*

The groundmass is composed of minute augite prisms, small laths of plagioclase as well as slightly larger crystals of plagioclase that are much less calcic in composition than the large phenocrysts, with shells of alkalic feldspar around them; small crystals of orthoclase, little square and rectangular crystals that have the general appearance and habit of nephelite and imperfect dodecahedral crystals of h  ynite showing strongly marked cleavage with inclusions oriented along the cleavages and distributed in fine dust-like particles that make some of the crystals almost opaque (Fig. 3). These crystals of h  ynite are surrounded with a shell of isotropic substance that may possibly be of slightly different composition, and into which the cleavages do not usually extend. In addition, there are altered turbid spots that seem in many places to be interstitial in their distribution; these may be altered sodalite, although the identification is doubtful. Megascopically the rock is moderately porphyritic, dark gray in color, with abundant small phenocrysts of plagioclase and augite. A weathered exterior shell 1/16 inches thick surrounds the dark gray unweathered interior.

- *Specimen No. 2*, taken from another part of the rim of the crater, is also a tephrite. The phenocrysts of plagioclase are more abundant than the augite; they have a decided fluxional arrangement and they are clear and fresh, complexly twinned after the albite, pericline and Carlsbad laws and they exhibit zonal growth and contain crystal inclusions, glass inclusions and liquid and gas inclusions, all more or less well oriented. A few of the plagioclase crystals are slightly corroded, but resorption is not a prominent factor. Some of them are grouped so as to form compound phenocrysts and in some cases the individual crystals in the groups are slightly separated from one another by brown interstitial glass (Fig. 4). Very faintly pleochroic, beautifully idiomorphic crystals of grayish-green augite constitute the prominent ferromagnesian component of the rock. These crystals have moderate birefringence ($N^{\gamma} - N^{\alpha} = \pm 0.020$), with maximum extinction angles of 36° . They are optically positive, with notable dispersion, and occasional crystals exhibit very obscurely both the “hour-glass” structure and zonal structure.



Fig. 4. *Photomicrograph of Specimen No. 2. Ordinary Light, $\times 100$.* The groundmass is a reddish glass, black in the picture, filled with little rectangular crystals, judged to be nephelite, and minute needles of plagioclase. Clear unaltered phenocrysts of plagioclase and augite are both shown in the field, and in the center of the pictures a vesicle in clear colorless glass may be seen. An irregular patch of the same clear glass occurs in the lower right part of the photomicrograph.

The groundmass is composed of a reddish-brown glassy base filled with multitudes of little square, rectangular and hexagonal crystals that resemble nephelite, minute plagioclase laths, and a feldspathoid occurring in crystals that have a dodecahedral habit, in some of which cleavage is emphasized by oriented inclusions, whereas others exhibit the blue color characteristics of h  ynite; in addition, there are other euhedral, clear isotropic crystals that resemble analcite. Olivine and apatite occur very sparingly, but magnetite is a prominent accessory. The rock is decidedly vesicular, the vesicles always occurring in clear, colorless transparent irregular isotropic areas that look like glass and that have an index of refraction as high as the plagioclase crystals. This specimen differs from No. 1 in that it is somewhat more feldspathic, shows flowage much more distinctly and carries more glass in the groundmass. The hand specimen of No. 2 is darker and considerably more vesicular than No.1. The little plagioclase phenocrysts exhibit a directional arrangement due to flowage, and the h  ynite occurs in bluish crystals that are almost as large as some of the smaller feldspars. Both Nos. 1 and 2 have essentially the same chemical composition, as shown by the results of the chemical analyses, Table 1.

- *Specimen No. 3*, from the slopes of the volcano, is a vitrophyric tephrite whose groundmass is somewhat altered but whose phenocrysts are perfectly fresh, as are the tiny plagioclase microlites in the altered glassy groundmass. The rock is as vesicular as No. 2; the vesicles are always connected with and are distributed in colorless, isotropic, irregular areas of glass, similar to those in sample No. 2. The feldspar in this rock is confined to the groundmass through which it is distributed in the form of labradorite microlites. Pale, almost colorless augite, with moderate birefringence ($N^{\gamma} - N^{\alpha} = \pm 0.018$), moderately strong dispersion, optically positive character and with maximum extinction angles of 40° , is sparingly disseminated in idiomorphic crystals and groups of crystals. A feldspathoid with the habit of h  ynite is almost as abundant as the augite; the crystals are as large as the augite crystals and form one of the striking features of the rock. Most of them have good cleavage, some of the smaller ones carry oriented inclusions, and in a few instances, they show resorption effects. These blue crystals are so abundant in the hand specimen that their index of refraction was determined in the powdered rock by the immersion method. A number of determinations gave an index of 1.503 ± 0.005 , corresponding to a somewhat calcic h  ynite. The index is higher than the indices given for h  ynite by Larsen⁹ and Iddings¹⁰. Larsen gives 1.496 as the index of refraction of h  ynite; Iddings gives 1.4961 as the index of blue h  ynite from Niedermendig. Winchell¹¹ states that the index varies from 1.430 to 1.509, depending on the percentage of lime. A very small amount of magnetite, olivine and apatite occur as minor accessories, together with a strongly pleochroic light yellowish-brown hornblende.

⁹ Larsen, E. S., The microscopic determination of the nonopaque minerals, Bull. 679, U.S. Geol. Surv., 1921

¹⁰ Iddings, J. P., Rock Minerals.

¹¹ Winchell, N. H., and Winchell A. N., Elements of Optical Mineralogy, 1909

TABLE 1

	No.1	No. 2	No.3	No. 7
SiO₂	52.88	51.74	46.14	50.90
Al₂O₃	18.96	19.78	18.04	18.88
Fe₂O₃	2.92	3	6.73	1.82
FeO	2.88	2.03	1.44	3.20
MgO	2.22	2.26	4.91	2.61
CaO	6.40	6.33	9.28	6.45
Na₂O	5.09	5.24	5.08	4.76
K₂O	4.05	3.74	2.91	3.13
H₂O -	0.85	0.75	0.24	1.48
H₂O +	1.33	1.54	0.66	1.80
TiO₂	0.68	0.84	0.68	0.76
P₂O₅	0.42	0.52	0.98	0.78
SO₃	0.01	0.05	0.47	0.21
MnO	0.13	0.13	0.15	0.13
BaO	0.42	0.45	0.30	0.32
Total	99.24	98.40	98.01	97.23

Analyses by Ledoux and Company, New York City

NORMS

	No.1	No. 2	No.3	No. 7
Or	23.91	22.24	17.24	18.35
Ab	30.39	30.39	14.67	34.58
An	16.96	19.18	19.46	21.68
Ne	6.82	7.67	13.63	2.27
S. S.	-	-	0.85	0.43
Di	10.50	7.78	16.63	5.40
Ol	1.81	1.47	3.22	5.20
Mt	4.18	4.41	3.02	2.55
Il	1.37	1.67	1.37	1.52
Hm	-	-	4.64	-
Ap	1.01	1.34	2.35	1.68

No. 1. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.

No. 2. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.

No. 3. Vitrophyric Tephrite, II, 6, 3, 4. Salemore; slopes of volcano.

No. 7. Andesitic Tephrite, II, 5, 3, 4. Andose; 2000 feet down the slope.

This specimen differs from the other tephrites of this series in the presence of phenocrysts of h         instead of feldspar, in the restriction of feldspar to the groundmass, where it is distributed in the form of microscopic needles, and in the glassy character of the rock. The composition of the rock is likewise different as shown by the analysis, Table 1. Silica is lower, lime and magnesia higher and sulphuric anhydride is higher. These differences are reflected in the mode of the rock. The rock is dark red-brown in color, somewhat vesicular, very fine in texture, and contains numerous small, blue crystals of h         ranging in size from 0.03mm to 1mm, and larger phenocrysts of augite.

- ***Specimen No. 4***, also from the slopes of the volcano, is essentially an andesitic tephrite. It is porphyritic with a typical andesitic groundmass consisting of minute plagioclase laths of andesine make-up, arranged in characteristic flowage lines in a more or less isotropic base that is in part glass – the “hyalopilitic” structure exhibited by many andesites. The phenocrysts are large clear labradorite crystals that possess the usual complex twinning, large, pale augite crystals with a very moderate birefringence and brown basaltic hornblende, less plentiful than either the labradorite or the augite. Magnetite forms one of the prominent accessories, and apatite occurs in unusually large crystals that are more or less strongly colored violet-brown to smoky brown by included magnetite or ilmenite dust; in some places these inclusions are so concentrated as to render the crystal black and opaque in spots. H         is distributed through the groundmass in clear, isotropic small idiomorphic crystals that occasionally show a little resorption; the largest of these have dimensions of the magnitude of 0.25 mm. A few tiny square crystals doubtfully referred to nephelite are also scattered through the groundmass. The rock is slightly vesicular, and, like the other rocks of the series, the vesicles are commonly connected with irregular, clear, colorless isotropic areas that may be glass, but which in this rock have an index of refraction lower than balsam (< 1.535). The phenocrysts are considerably larger than those in the other samples and the rock is strikingly andesitic texturally, although the feldspars and the pyroxenes favor a basaltic composition. Megascopically the rock is very dark in color, strongly porphyritic, and very fine as to groundmass. The phenocrysts are moderately large plagioclase crystals attaining maximum dimensions of 6.0 mm, and augite crystals that are almost as large.

- ***Specimen No. 5***, likewise from the slopes of the volcano, has a very pronounced red color due in part to incipient oxidation of the glassy portion of the groundmass and in part to very abundant, minute red crystals disseminated in the groundmass. These crystals have monoclinic forms, strong birefringence, and strong relief. Most of the crystals have approximately parallel extinction, but occasional ones gave angles as high as 12° , dependent on their orientation. They exhibit strong absorption in a direction perpendicular to their elongation, in this respect behaving like tourmaline. Occasionally one crystal penetrates another, simulating the cruciform twinning of staurolite; these are probably accidental penetrations, however, and not twins. They are red-brown in color, but the color is spotty and variable in distribution. They may be iron-rich amphibole or pyroxene crystals, with an unusual absorption behavior, but we are not certain of their identity. They are very minute and do not give any very satisfactory optical reactions. The rock is otherwise normal in its make-up, consisting of basic plagioclase both as phenocrysts and as small laths in the groundmass, arranged in flowage lines; light-colored augite with moderate birefringence, very sparingly distributed; and magnetite, olivine, apatite, and yellowish-brown, beautifully pleochroic basaltic hornblende as accessories.

No feldspathoid minerals were observed in this rock, which differs in this respect from all of the other specimens submitted. The rock is a normal basalt. The feldspar, pyroxene and hornblende are perfectly fresh; all of the oxidation is confined to the groundmass. Even the olivine is but slightly attacked, some of it exhibiting rims of limonite. The fine dark red-brown groundmass of the specimen has suffered incipient oxidation, but all of the phenocrysts are fresh and unaltered. Like the other lavas of this series, the rock is vesicular, some of the vesicles being in a colorless glass whose index lies very close to 1.535.

- *Specimen No. 6*, taken from the sediments near the east base of the volcano Sumaco, is entirely different in origin and composition from all the other eight samples. This is a fossiliferous limestone containing foraminifera, bryozoa, shell fragments, all replaced by calcite, and yellow to brown fragments that may represent the carapaces of crustacea. It is difficult to identify the fossils in thin section, but *Globigerina*, *Nodosaria*, *Cyclamina*, *Gümbelina*, *Textularia* and *Bryozoa* were recognized. These forms are distributed in a fine carbonate matrix that is turbid with what is probably argillaceous matter. Considerable pyrite is distributed through the rock in fine granular aggregates, as individual crystals, and in veinlets; small black grains, that may possibly be bituminous matter, are sparingly disseminated. In places, some of the pyrite has oxidized to reddish-brown limonite.

- *Specimens Nos. 7, 8 and 9*. All of these samples were collected from the slopes of the volcano; No. 7 came from a point about 2000 feet down the slope. They are all andesitic tephrites with essentially the same compositions, and with only slight textural differences. The groundmass of No. 7 is partly glassy, with fine needles of moderately basic plagioclase feldspar and minute prisms of green augite distributed through it. The groundmass, consisting of a glassy base and thickly disseminated matted needles of plagioclase, and minute augite prisms, has the "hyalopilitic" structure common to many andesites. This feature is especially striking in specimen No. 8; the groundmass of No. 9, however, is composed of somewhat larger plagioclase needles than those distributed in the glassy bases of Nos. 7 and 8, although even No. 9 is also beautifully hyalopilitic.

All of these specimens are moderately porphyritic. The phenocrysts consist of large, clear, plagioclase crystals that have compositions ranging from basic andesine to labradorite; they are complexly twinned after the albite, Carlsbad, pericline, and in a few cases, the Baveno laws. Many of them exhibit zonal growth and a zonal distribution of inclusions. The plagioclase microlites in the groundmass are more acid than those constituting the phenocrysts. Augite occurs both as phenocrysts and as minute prisms in the groundmass in all three of these rocks, and all carry a little brown basaltic hornblende also. The hornblende, more especially in No. 9, has been partly resorbed with the development of finely granular magnetite as a resorption product. Häüynite is an accessory common to all three of these rocks. In Nos. 7 and 9 it is slightly brownish in color, with very dark margins and pronounced cleavage in some instances (Fig. 5). The häüynite in No. 8 is not so plentiful; the color is pale blue, with deeper blue margins; even the brownish häüynite, especially in No. 7, is occasionally slightly bluish in the centers. Unusually large crystals of brown apatite form very striking accessories in all three of these rocks, and magnetite is a prominent component.

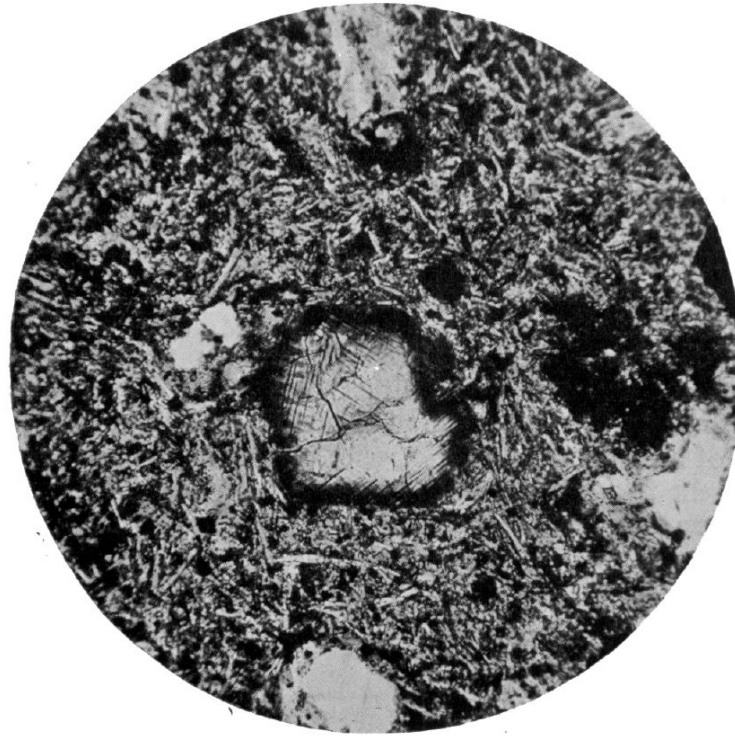


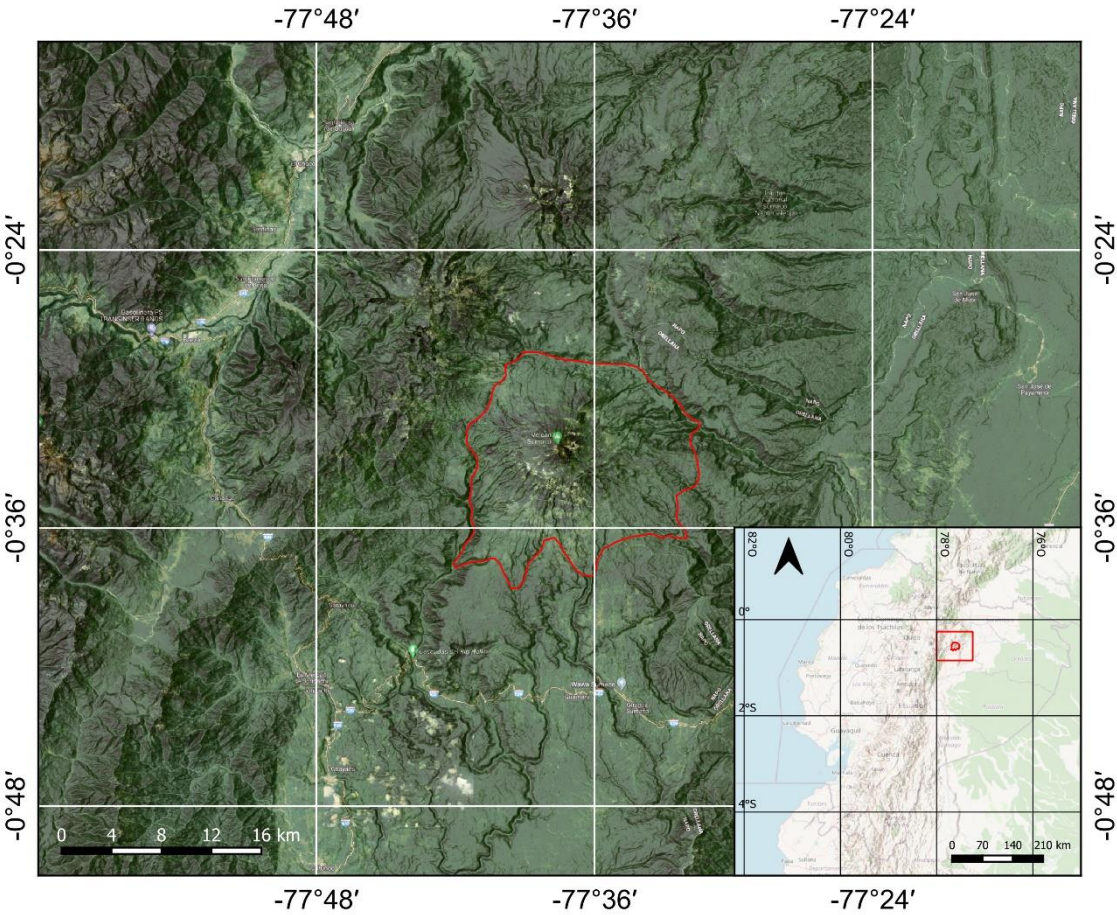
Fig. 5. *Photomicrograph of Specimen No. 7. Ordinary Light, $\times 100$.* Taken at the higher magnification of 100 diameters in order to show the details of one of the h  ynite crystals, with its very dark margin, and incompletely developed cleavage. The character of the groundmass is a little more plainly exhibited, also.

Megascopically No.7 is moderately porphyritic, very fine texture as to groundmass, dark gray in color, with phenocrysts of plagioclase up to a centimeter in length, and of augite ranging in size to 7mm as a maximum. No. 8 is essentially the same as No. 7, but the augite is not so prominent. No. 9 is similar to Nos. 7 and 8. As may be seen from the chemical analysis, No. 7 is strikingly similar in composition to Nos. 1 and 2.

Comment on Analyses

The chemical analyses, Table 1, of Nos. 1, 2 and 7 are similar, but No.3 has lower silica, higher lime, higher magnesia and higher combined iron oxides. The total alkali in Nos. 1 and 2 is about the same, nine percent approximately, whereas in Nos. 3 and 7 the total alkali is about eight percent. In other respects, Nos. 1, 2 and 7 are nearly alike in composition, especially in their content of lime, magnesia, alumina and approximately of silica and total iron oxides. All of the rocks carry a little sulphuric anhydride which, together with the high alkali, the lime and alumina, is reflected in their mineralogy by the presence of the feldspathoid h  ynite and by the probable presence of nephelite as the minute crystals mentioned in the description of these rocks. Potash is higher than usual in rocks of this general composition, occurring in part as shells or coatings of orthoclase on some of the plagioclase phenocrysts, in part as little crystals of orthoclase distributed through the glassy base of the rocks, and probably in part in "occult" form in the glassy base. Nos. 1, 2 and 7 are andesitic, whereas No. 3 is basaltic. According to the Quantitative System nephelite occurs in the norm of all four of the rocks, with olivine and diopside. The prominent feldspathoid in the mode is h  ynite, with nephelite of less certain identification.

Location map of the volcano Sumaco



[American Geographical Society, Geographical Review, Vol. 19, No. 2, pp. 201-217]

IN THE LAND OF CINNAMON: A JOURNEY IN EASTERN ECUADOR*

by

JOSEPH H. SINCLAIR

* On this expedition I was accompanied by my wife. Our thanks are due not only to the American Geographical Society for its coöperation but also to the government of Ecuador, whose president, Dr. Isidro Ayora, heartily sympathized with our efforts, to the State Department at Washington, and to the New York Times.

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INTRODUCTION

In the year 1539 the Marquis Don Francisco Pizarro, being in the city of Cuzco, received tidings that beyond the city of Quito, and beyond the limits of the empire formerly ruled by the Incas, there was a wide region where cinnamon grew; and he determined to send his brother, Gonzalo Pizarro, that he might conquer such another land as the Marquis himself had found, and become governor of it¹.

The disasters attending Gonzalo Pizarro's expedition early proved the difficulties of conquering the Land of Cinnamon – the dense forests, the fall – impeded rivers, the appalling weather: in the “provinces” of Quijos and Sumaco, say the chronicles, “during two months it did not cease to rain for a single day.”

Into this Land of Cinnamon the writer and Mr. Theron Wasson had penetrated in 1921. In the course of our journey the exact position and the height of the great isolated cone of Sumaco had been determined, but it had not been possible to approach the mountain within 30 miles². The mapping of Sumaco remained an allurements; and September, 1927, saw the writer back in Quito en route to the Oriente.

PLANS FOR SURVEY WORK

It had been our intention to run a traverse line from Quito eastward over the Guamaní Pass to the volcano Sumaco and then, after mapping the cone, to explore the unknown region to the north of this mountain. But on our arrival in the capital, we received news that there had been a violent volcanic eruption eighteen months or so ago somewhere east of the Andes, that the sound of great explosions had been heard, and that for a number of days the sky had been colored by fine ash. The Director of the Astronomical Observatory told us that he had observed the center of the clouds of ash to lie on a line from Quito passing south of the snow-capped Cayambe (see Fig. 1). It was plain from this and other information that an unknown volcano had come into activity. We decided to modify the Sumaco program and try to locate this new volcano.

¹ The Expedition of Gonzalo Pizarro to the Land of Cinnamon, A.D. 1539-1542, translated from the second part of Garcilasso Inca de la Vega's "Royal Commentaries of Perú," in: C. R. Markham: Expeditions into the Valley of the Amazons, 1539, 1540, 1639, *Hakluyt Soc. Publs. Ser. I*, Vol. 24, London, 1859, pp. 3-20.

² J. H. Sinclair and Theron Wasson: Explorations in Eastern Ecuador, *Geogr. Rev.* Vol. 13, 1923, pp. 190-210.

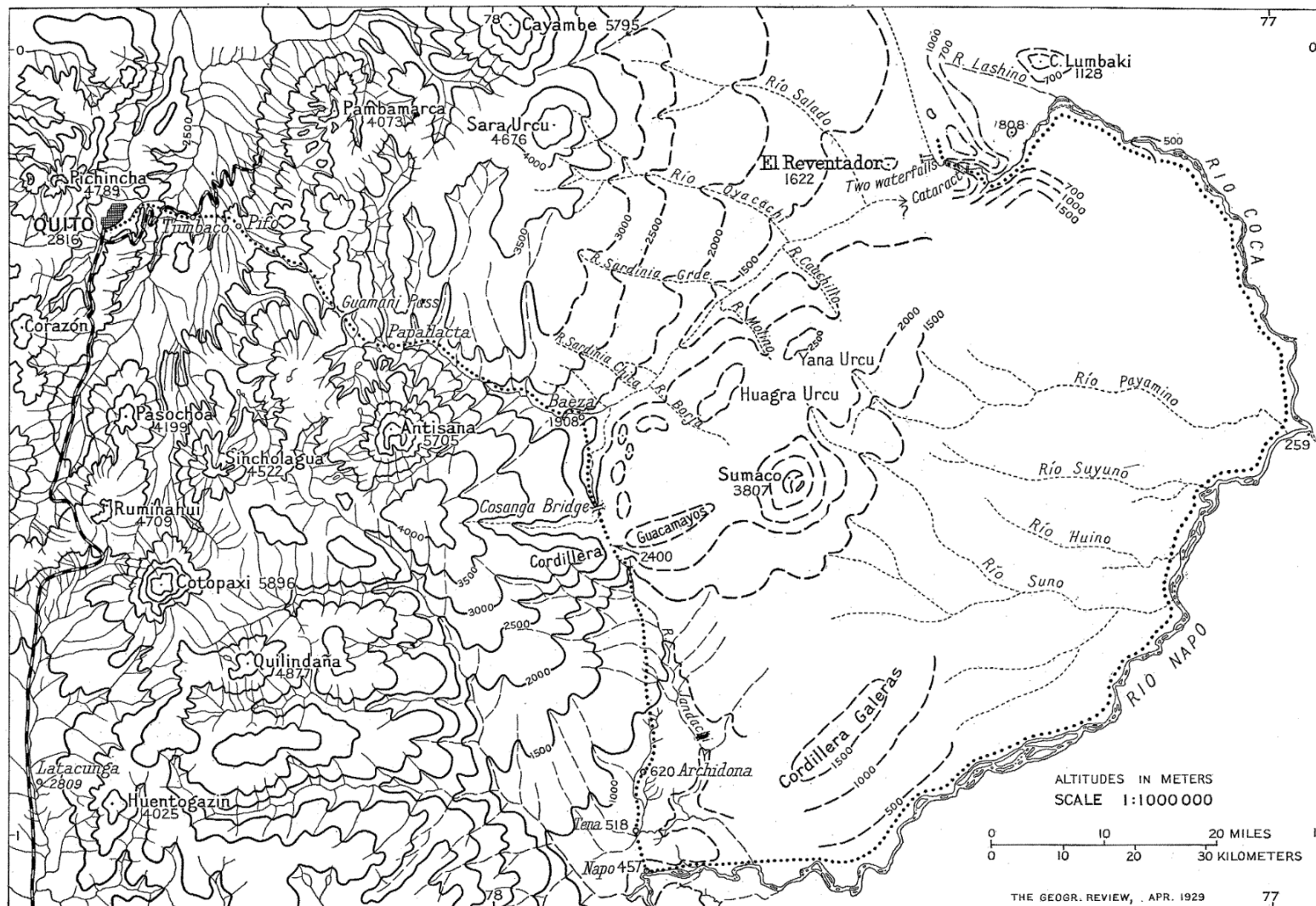


Fig. 1 – Map of a part of eastern Ecuador based on the compilation prepared for the Quito and Iquitos sheets of the American Geographical Society's Millionth Map of Hispanic America, showing the route of the Sinclair Expedition of 1927-1928.



Fig. 2 – View looking north from Hacienda Paluguillo (9432 feet) on the Papallacta trail showing the volcano Cotopaxi at the left and the treeless plains of the Ecuadorean highlands.

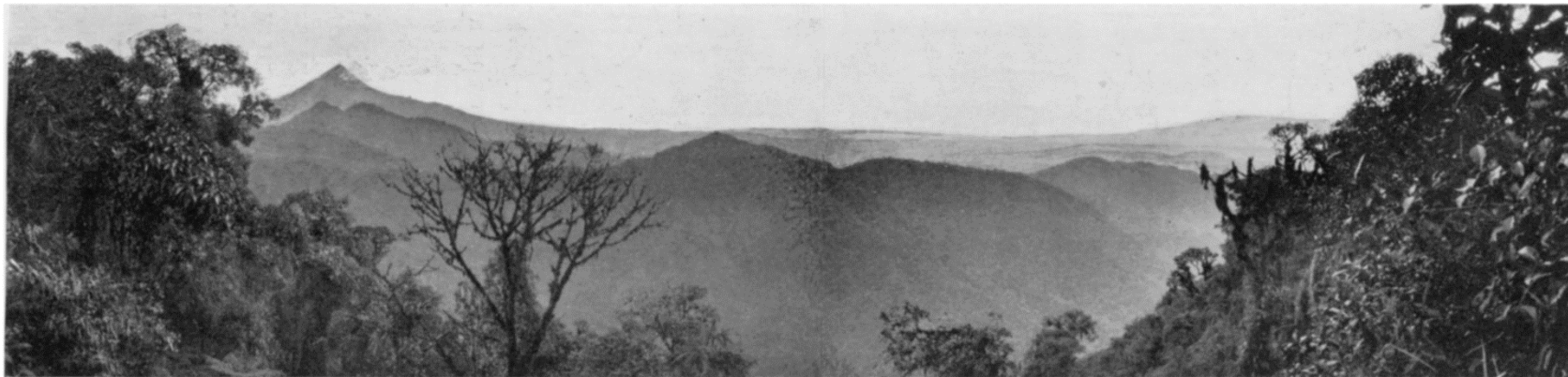


Fig. 3 – View looking east over the Amazonian lowlands of eastern Ecuador from the crossing of the Cordillera Guacamayos by the Quito-Napo trail (7870 feet). At the extreme left the volcano Sumaco (12486 feet); at the extreme right the Cordillera Galeras (about 5000 feet).

From my previous experience of the weather in eastern Ecuador, similar to that of Gonzalo Pizarro, I decided not to try to obtain latitude and longitude positions by the usual methods, which involved carrying a heavy transit for star observations and a radio outfit or chronometer for securing time – and incidentally many sleepless nights waiting to observe stars which only now and then peeped between masses of cloud. Instead, I proposed to survey our route eastward from the observatory of Quito, whose latitude, longitude, and elevation were known to be respectively, $00^{\circ}12'55''\text{S}$, $78^{\circ}29'33''\text{W}$, and 9236 feet above the sea, by using a 15-inch traverse table to which were attached sheets of drawing paper, and a Gurley telescopic alidade equipped with magnetic needle and telescopic wires for securing distances by reading stadia rods. The initial magnetic variation of $6^{\circ}34'$ E was found at Quito against the true north-south line established by the observatory. We were able to use the stadia rod not only to secure distances but also to carry an exact line of levels from the vertical angles read at each sight, to a point 55 miles east of Quito where we entered the forests. After entering the forests the plane table was used but the distances were obtained by a cotton tape 300 feet long treated with paraffin, and the elevations by a Paulin barometer. The Rio Coca for a distance of about 65 miles was also surveyed by stadia. The plane table outfit enabled us not only to map our route accurately but to secure topographic data on either side of the main route by intersections of points and reading vertical angles to these.



Fig. 4 – On the Papallacta trail on the western slope of the Andes about 12000 feet elevation

FROM QUITO INTO THE QUIJOS VALLEY

The start from Quito was made on October 3. The first 14 miles of road, passing the good-sized villages of Cumbayá, Tumbaco, and Pifo, can be used by automobiles, and the remaining 42 miles to Baeza can be negotiated with pack animals. A few miles beyond Pifo is Paluguillo, the *hacienda* of our friends Sr. and Sra. Francisco Pérez G.

It is situated at an altitude of 9452 feet and is the last habitation until Papallacta is reached. The ranch itself extends far into the mountains. The valley, up which the road runs, is wide and walled in by high ridges of volcanic rock. We made our first camp at 11338 feet, the vegetation here being limited to coarser grasses. The Guamaní Pass was crossed at 13354 feet. A mile and a half beyond the summit is the beautiful lake Sugchoscocha, whose outlet constitutes one of the affluents of the Papallacta River; and three and three-quarter miles farther is Lake Papallacta. Both lakes are narrow, about a mile in length, and apparently formed by lava dams. The tree line of the eastern slope may here be drawn at 11400 feet. About six miles from the pass is the village of Papallacta (elevation 10333 feet), reported to contain some 300 inhabitants; but probably this figure includes all the residents of the “parish” of Papallacta and not the village alone which, as far as we could see, contained but a few houses. The inhabitants are very poor and are of mixed Indian and Spanish blood. The village, which lies in a deep gorge, is only seven miles due north of the summit of the great ice-covered mass of Antisana, which towers to an elevation of 18700 feet above the sea. But we did not get even a glimpse of it while here, for it was covered with mist. The road was excellent for horseback travel, as it had been all the way from Pifo; but the Chalpi bridge, four and a half miles east of Papallacta, and a large part of the government’s improvements on this trail were destroyed in the floods of February, 1928.



Fig. 5 – Sumaco seen from the summit of the Cordillera Guacamayos, 18 miles distant. Compare the view of the other side of the mountain by Commander George H. Dyott, who visited Sumaco in 1925 and secured rock specimens (Fig. 2 in R. J. Colony and Joseph H. Sinclair: *The Lavas of Sumaco Volcano, Eastern Ecuador, South America*, *Amer. Journ. of Sci.*, Ser. 5, Vol. 16, 1928, pp. 299-312).

Some ten miles from Papallacta we were joined by our old friend Manuel Rivadeneira of Napo who was en route with his son-in-law to Quito. In the course of the evening Rivadeneira agreed to make a forced journey to Quito and return to join us. Meanwhile we continued down the river to the confluence of the Quijos and the Papallacta where was obtained a magnificent view of the gorge of the Quijos from the trail several hundred feet above the rivers. We also had our first view of Antisana, whose snow-capped summit just showed above the tops of the near-by wooded ridges. A short distance below this point the south side of the valley of the Quijos is formed for several miles of great cliffs, over which tributary streams cascade. Fifty-four miles from Quito the trail crosses to the right bank of the Quijos River by an excellent bridge constructed in 1924. One-half mile below the junction with the large affluent called the Guagrayacu we came to a cable crossing over the Quijos River, used, we were informed, by several Indians who had small farms a few miles below. Here the *teniente político* of Baeza, who had come to meet us, told us that the volcanic eruption noted at Quito had not only been observed in this vicinity but that ash had fallen over the entire region and that the flames and noise of the explosions had spread terror among the inhabitants, both Indian and white. Obtaining the direction of the point of eruption from several other reliable witnesses and plotting the bearing to this on our map, we found that it joined the bearing from Quito in latitude 0°8'S and longitude 77°33'W.

A study of the conditions from the heights on the south side of the Quijos showed that this valley extended many miles northeast and that the volcano, now more exactly pointed out, must be very close to the river, there known as the Coca, and about 35 miles northeast of where we were. It was agreed that the best way to proceed was to follow the north side of the Quijos Valley, to do which we had to gain the left bank by means of the precarious cable crossing.

The torrential character of the Papallacta and Quijos rivers from Papallacta to the cable crossing is shown by the fact that between these two points the fall amounts to 4470 feet, an average of 210 feet per mile. As will be noted later, the final gradient of the Coca, formed by the above-named and other affluents, amounts to only 19 feet per mile, taking the 59 miles above the mouth of the river, i.e. between an elevation of 850 feet above the sea and 1977 feet. The only other river in eastern Ecuador whose gradient has been carefully studied is the Pastaza, which between Ambato on the Andean Highland 8516 feet above the sea and Mera, at the base of the Andes, 3808 feet above the sea, a distance of 87 miles, averages a drop of 54 feet per mile.

At the first house below the cable crossing, occupied by a woman named Mariana Descobar, we decided to await Rivadeneira. However, we soon saw that it would be impossible to continue down the Quijos, for it was impossible to get Indian packers. In this respect our experience was merely a repetition of that of all travelers in the region east of the Andes of Ecuador. We had not expected it to be our lot because of the official interest in our expedition; but, although the government had issued orders to Papallacta and Baeza, the authorities there would not or could not secure the Indians to help us. Rivadeneira, who had rejoined us, started on foot to Quito again to obtain help. In the meantime, we moved camp upstream, across the cable crossing to the right bank, and carried on the survey to a point about a mile beyond Baeza (elevation 6260 feet) on the trail to the Napo. We found Baeza to consist of about three huts situated on a low and rather flat spur of a ridge and in a situation favorable for a small village. We were informed that the old Baeza was farther up the ridge and that a number of Indians still lived there.

ROUTE CHANGED TO THE NAPO

Rivadeneira arrived on the 30th but with only a few Indians, one of whom fell on his knees when he came to our tent and begged not to be taken to the terrible volcano to die. The next day failed to bring the additional Indians promised, and we definitely abandoned the project of descending the Quijos-Coca Valley from Baeza. Rivadeneira believed that there was a possibility of reaching the volcano from the opposite direction, i.e. the east, by proceeding about 50 miles south of Baeza to the Napo River, over the famous or rather infamous Papallacta trail, then descending the Napo 100 miles to the mouth of the Coca, whose position we had accurately determined in 1921, and ascending this river. No one knew how far up the Coca canoes could be poled; but, as this program involved new mapping from Baeza south to the southern base of the Cordillera Guacamayos, which we had reached in 1921, and new exploration on the lower reaches of the Coca, we decided to proceed on this program. Later results proved that we accomplished as much in this move, and perhaps more, than we should have accomplished in the straight descent of the Coca Valley from Baeza.

On November 3 we took up the traverse where we had abandoned it on October 27, reaching a point on the newly-made road about two miles south of Baeza. During the day we succeeded in locating by triangulation the house of Doña Mariana Descobar on the heights bordering the left bank of the Quijos. Vertical angles made this 6035 feet above the sea, while the average of the barometer readings while we were camped there on October 24, 25, and 26, was 6090 feet, the barometer readings, as usual of 10:30 a.m. each day, thus being not greatly different from the true elevation. This house three miles below Baeza, accurately located and with an elevation accurately determined, is an important reference point in future attempts to explore the stretch of the Coca River unmapped by us in 1927.

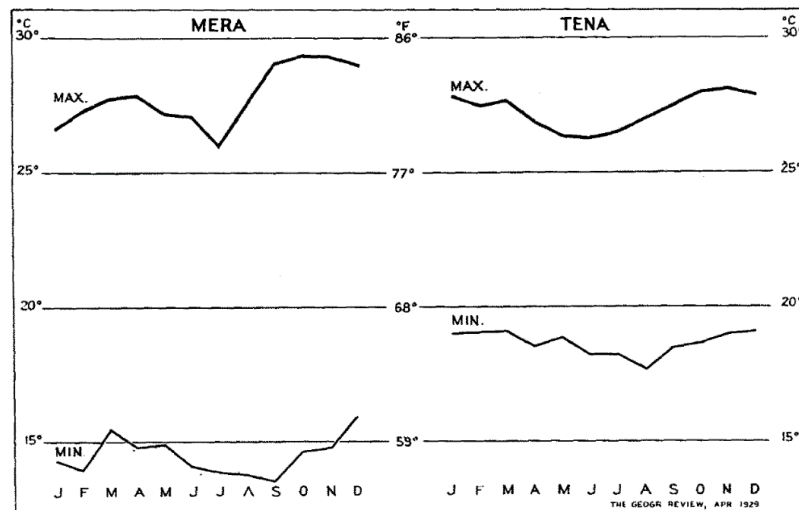


Fig. 6 – The graph to the left shows mean maximum and minimum temperatures at Mera (3800 feet) for 1926 and 1927, based on meteorological observations by Charles Newdeck. These and other records by Herr Newdeck are on file at the American Geographical Society. Mean maximum for the year about 82° F; mean minimum 58°.

The graph to the right shows mean maximum and minimum temperatures at Tena (1700 feet) for the years 1925 and 1926. Observations by the Josephine Fathers.

The following day we entered the dense forests and proceeded by a trail which for 50 miles cannot be described by any better term than "mud wallow". On November 9 we reached the place where the Cosanga, formerly crossed by a cable, was now crossed by a bridge suspended by steel wires about 40 feet above the roaring torrent here 150 feet wide. The bridge, however, had become so dangerous from lack of repairs that its use had been abandoned, the Indians fording the stream about half a mile above the bridge. Leaving the main expedition to follow, I led the way to the ford with three others and, by joining hands and wading in the swift current in water up to our necks, we crossed the Cosanga. The river continued to rise, and the rest of our party were compelled to resort to the bridge, dangerous as it was.

On the 12th we crossed the Cordillera Guacamayos, called by the Indians "Rumi Urcu" or mountain of stone, at an elevation of 7870 feet above the sea. The trail ascending this is in a narrow crevice cut down by the wearing of many feet through centuries of travel to a depth of about ten feet and so narrow that one could hardly drag his body through. It was knee-deep in mud and had been transformed by the torrents of rain into a watercourse.

On the morning of the 13th the weather happened to be clear and before the fog closed in afforded us a panorama of wild beauty. To the east, 18 miles distant, rose the great cone Sumaco towering to an elevation of 12486 feet above the sea. To the right of this was a vast expanse of tropical forests and to the extreme right and about 28 miles distant could be seen the summits of the Cordillera Galeras, situated north of the Napo and a few miles northeast of the mouth of the Misahuallí. Even before we could finish taking two photographs the mist fell over Sumaco.

ARCHIDONA, TENA, AND NAPO REVISITED

On the 15th we camped on the right bank of the Jandachi where Wasson and I had camped in October, 1921. We could now proceed full speed to the confluence of the Coca and Napo rivers without the necessity of carrying on survey work. On the 17th of November we struggled through the seven miles of deep mud to Lara's house, the first inhabited house we had seen since leaving Baeza, 32 miles distant. The next day brought us to Archidona: the first half of the way was indescribably bad; but about four miles from Archidona we reached a really fine piece of road recently constructed, which continued in the midst of small farms to the pueblo. Archidona in 1927 was almost exactly the same as in 1921 except that a church and school had recently been constructed by Italian priests and nuns of the Josephine order.

The Papallacta Indians who had served us so well were now allowed to return home after we had given them money and presents. They told us we were by no means as bad as we had been painted!

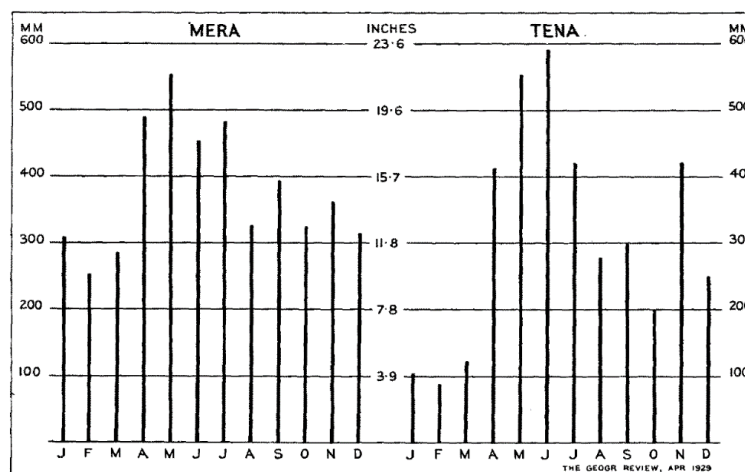


Fig. 7 – The graph to the left shows average rainfall at Mera for the years 1922-1926. The rainiest year, 1922, had 220 inches; the driest, 1926, had 149 inches.

The graph to the right shows rainfall at Tena for 1925, when the total fall was 147 inches.

On the 18th after securing a new supply of Indian packers through the help of Señor Serrano, *Jefe político* of the district, we rode horseback to the Napo River 10½ miles distant, fording the Misahuallí River and passing through the village of Tena. The Josephine padres established a mission at Tena in 1925. There is also a school conducted by two or three Italian nuns of the same order. At the mission headquarters has been established a meteorological station (altitude 1700 feet) which has, next to Mera, furnished the best data on climatic conditions in eastern Ecuador. Observations for 1925, 1926, and the first six months of 1927 show an average yearly minimum temperature of 65.3°F and an average yearly maximum of 81.3°F, the mean annual temperature being about 73.3°F. The rainfall in 1925 totaled 147 inches. For eleven months of observations in 1926 there was an average of 6.66 inches per month, which would be equal to a total of 80 inches for that year. During the period January-June, 1927, there was a total of 107 inches, an average of 18 inches per month, which if continued during the year would amount to 200 inches. Since our visit in 1921 there has also been established about a mile from the village on the bank of the Misahuallí a Protestant mission under the direction of Mr. and Mrs. Larsen. In addition to these institutions the village consists of only about half a dozen houses.

At Napo we were the guests of Manuel Rivadeneira and his family. In 1927 Napo consisted of about five houses, including a church recently built by the Josephine padres who come from Tena from time to time to conduct services. Next to Manuel Rivadeneira, the most prominent resident was an Australian trader who had married an Ecuadorian. We were told that an American resided about a mile down the river but did not have the pleasure of making his acquaintance as he and Rivadeneira were not on good terms. The personal feuds of the few residents in eastern Ecuador add no little to the difficulties of penetrating the country. They arise largely through trouble in securing labor, there being not enough Indians to go around. The other residents of Napo were Ecuadorians with a few Indian servants. As in Tena and Archidona, the Indians live in their huts along the banks of streams away from the villages, where in *chacras*, or small clearings, they raise yuca and plantains, their main food.

The elevation of Napo is only known by barometer. The best determination, we believe, is that based on the average of 12 days' readings of our Paulin barometer at about 10:30 a.m. At this hour we found, from the stadia survey made by us from Quito to about three miles south of Baeza, the readings of the Paulin barometer coincided nearly with the true elevation as obtained by vertical angles. The readings at Napo of about 10:30 a.m. on November 18-26, 1927, and January 2-6, 1928, averaged 1500 feet, which is probably not far from correct. James Orton, who visited Napo in 1865, made the elevation 1450 feet. In 1921 we had determined it at 1680 feet, but this figure was arrived at by taking the mean of all the barometer readings, which with increase of temperature during the day reach a maximum in the afternoon giving an elevation much above the true value.

DOWN THE NAPO TO THE COCA

At Napo we had a great deal of difficulty in securing canoes and Indians for the expedition 100 miles downstream and up the unexplored Coca. But finally on November 26 with three canoes and a large number of Indians and with Manuel Rivadeneira and his son-in-law, Jacinto Bejarano, the *teniente político* of the Coca, we pushed off into the current and were soon racing through the rapids, swollen by the recent rains. Five miles below we came to the whirlpool "Remolino de Latas", " where we had to stop and wait for the waters to recede. On a hill standing on the left bank just above the whirlpool is the home of an Ecuadorian woman pioneer, Juana Arteaga; and here we were welcomed cordially and remained in the shelter of a good house till the 28th when the river had lowered sufficiently to allow the canoes to be roped down the rapids. Cotton and coffee are raised on the little farm, and in addition the flowers of the cinnamon tree called "Ishpingo" are gathered and sold in Quito for about 40 cents (American money) per pound. This tree, which is a little larger than a walnut tree, grows to a diameter of 80 centimeters. It is native all along the Napo River for about 200 miles below Remolino de Latas. The bark is also used. It is the famous "canela" that lured Gonzalo Pizarro to the Land of Cinnamon. The coffee raised here is sold in Quito for about \$14 per 100 pounds. Cotton brings \$18 per 100 pounds in Quito or Ambato. Yuca, the great foodstuff of eastern Ecuador, is also grown, together with the usual plantain.

On the 29th we arrived at the confluence of the Napo and Coca rivers. We were now 3000 miles from the mouth of the Amazon, only 850 feet above the sea, and the river was half a mile wide. With a steam launch we could sail to the Atlantic.

ASCENT OF THE COCA

Preparations for the ascent of the Coca River had been already started by sending Bejarano ahead to secure Indians on the Payamino River. After a preliminary stadia traverse of $5\frac{3}{4}$ miles up the Coca from the mouth on December 1, we broke camp early on December 2 and started upstream with the two canoes, leaving word for Bejarano to follow us when he arrived with the Payamino Indians. The Coca here, like the Napo above the mud bank stretch, is a braided stream of many channels and islands and with low banks. We noticed during the day three animals about two feet long, which Rivadeneira called "mitias" (the nutria or coypus?). He said these were amphibians and that their fur was very fine.

Bejarano reached us on December 3 with a number of Payamino Indians, and some of the Napo Indians were allowed to return. We continued poling upstream for seven days more, arriving on December 9 at the mouth of the Lashino River, 45½ miles from the mouth of the Coca. The rapids as we progressed upstream became more numerous and more dangerous. The Indians, however, were kept in good humor as we stopped from time to time to allow them to fish with their nets in blind elongations of the river where there was no current. They caught one strange fish about three feet long with long white whiskers. Rivadeneira called it a “bagre blanco” and said that a similar fish is also found in rivers on the west coast of Ecuador³. Most of the fish caught were “boca chica” or “chagua”, a sucker type of fish also known, said Rivadeneira, in the rivers of the west coast. Another type of fish, “karachama”, was found underneath rocks. It had a sucker-like mouth with an undershot jaw. In the entire stretch of 45½ miles to the Lashino we had not seen a habitation or even an Indian, but evidences at the mouth of the Lashino indicated the near-by presence of Indians. It was decided to remain here and reconnoiter, and on the 10th we discovered a camp of Cofanes, far up the Lashino. Four of these Indians came- with us to our camp and agreed to assist us in ascending the Coca, which they said was unknown to them above this point. We remained at the camp till the 12th to enable the Cofanes to prepare for the expedition by toasting large amounts of plantains. The Cofanes differ from the Indians who dwell on the Napo and Payamino rivers in several characteristics beside language. The men wore long gowns made of the bark of trees and had their hair cut very short, in addition plucking the hair of the eyebrows and eyelashes. They were strongly built and proved to be able and willing helpers.

On December 7 we had caught a glimpse of a lofty isolated mass which we thought might be the volcano. This proved to be an unknown mountain, “Cordillera Lumbaki”, almost exactly on the equator and standing isolated on the Amazon lowlands. Landslides had exposed near the summit cliffs of bare rock, and we later saw that these were composed of eastward dipping sedimentaries.

The rapids had now become almost continuous and very dangerous. On December 14 we reached the end of canoe navigation. We had arrived at the uppermost part of the braided portion of the Coca: above this point it is a single stream encased in a narrow and deep gorge. We unloaded the canoes, dragged them to what seemed a safe place above ordinary high water, and tied them securely to bushes. Then we moved to a camp site about a mile above, near the base of cliffs 375 feet high. So far we had seen no signs of the volcano, and from the appearance of the canyon we could not expect to ascend it even on foot. Rivadeneira with a few Indians left to attempt to scale the cliffs and proceed west on the ridges. He returned two days later to report the country composed of great canyons all bounded by vertical walls in which he had only been able to struggle a few miles west. In the meantime Bejarano had made a successful attempt to ascend the river a few miles by following the water’s edge. It was therefore decided to leave Mrs. Sinclair and Manuel Rivadeneira, who was badly injured by a fall, with most of the Indians, some of whom were ill, and to take the Cofanes and Bejarano and proceed as far as possible up the canyon.

³ No lowland species of fish occurs on both sides of the Ecuadorian Andes, but in some cases the genera are identical. Mr. Arthur W. Henn, curator of ichthyology in the Carnegie Museum, who was consulted in the matter, writes: “The ‘bagre blanco’ is some kind of catfish which has relatives on the western slope. The ‘boca chica’ of the western slope is *Prochilodus humeralis*, with a different species of *Prochilodus* in the Oriente. The ‘karachama’ I cannot identify; but it is probably a member of the Loricariidae, or mailed catfishes.”

On the 18th we carried our survey up the Coca another three and a half miles, passing a large canyon coming in from the south. It rained all day, and next morning the view upstream was still obscured by fog. We started again but proceeded a little less than a mile when we had to leave the river and make our way through the jungle above the cliffs, which impeded our progress at water level. The stadia survey of the Coca thus ended 58½ miles from its mouth at an elevation of 1975 feet above the sea. The survey from this point was continued by alternation of tape measurement, stadia, and pacing. About 60 miles from its mouth the entire Coca River plunges over a fall about 50 feet high in a narrow crevice in the rocks, here igneous. Above the cataract on the right bank through an opening in the trees we had a view of a magnificent cataract formed of a side stream plunging 1300 feet into the Coca. The top of another great cataract could be seen upstream.

The canyon had now become so wild and deep that further ascent scarcely seemed practicable. We decided, however, to make a final effort in spite of continuous rain and fog. About 61 miles from its mouth the river made a great bend to the south. We entered the forests and after a six hours' struggle reached the top of the ridge in our front, 1400 feet above the valley bottom. At dawn of December 21 the mist lifted just above the canyon rim to reveal two great cataracts leaping in three jumps into the 1500-foot-deep abyss below; but hardly had we taken two exposures with the camera when the mist lowered. On the strength of having shot a big black monkey and the certainty of having a good feed that night, the Indians agreed to continue another day.



Fig. 8 – Cofanes Indians on the Coca River.

We moved north about three miles, following the ridge and ascending additional escarpments of sedimentary rocks with cliff faces, and shortly after noon were 1000 feet higher. We had kept near the rim of the canyon all the time. At a favorable spot we put all hands at work cutting down the trees that impeded our view over the cliffs, and as these fell one by one we obtained a surprising view of the country to the north and west for many miles. When the mist had retired from all but the summits of the Andes we discovered that we were on a lofty mesatopped mountain of nearly 5000-feet elevation which dominated the region to the north, west, and southwest. Evidently it was the mesa we had sighted on December 12, which, owing to the extreme humidity of the atmosphere, had then appeared far higher and more distant. Cayambe was 36 miles to the west. The great gorge which we were following could be distinguished coming in a straight line from far in the north, but we could see no signs of the bend necessary if this river were the one which we had seen flowing northeast at Baeza. But if this were not the main Coca, how account for the great amount of water and the large canyon, and where did we lose the main stream? It will take some additional exploration to determine this interesting question. The cataracts together furnished sufficient water for a large enough river, but we cannot be certain that these represent the divided channel of a single stream as we first thought. The only other solutions are the canyon we had passed on December 18 or a possible junction at the big bend which we could not see.



Fig. 9 – View up the Coca River from the point where canoe navigation had to be abandoned, 55 miles above the mouth.

EL REVENTADOR

While we were examining the country to the north and west, the Indians felled a monarch of the forest to our left which dragged with it down the cliff walls several other trees, and we heard the call “El volcán”. Turning, we saw about six miles southwest an isolated mountain composed of a number of sharp and jagged peaks, the highest rising to an elevation of over 5300 feet above the sea. With a small cone-shaped peak a few miles to the south it alone broke the monotony of the rolling forests in the sweep of country before us from the base of Cayambe to the Andes west and southwest of Baeza. This distinctive topographic feature, so unrelated to the general physiography of its surroundings above which it rose for over 1000 feet, coincided with the position of the eruptive center which we had located approximately from bearings taken at Quito and Baeza. As far as could be determined without standing on it and gazing down into the crater of which the peaks probably formed the broken walls, this was the volcano “El Reventador” whose explosion had filled the sky of Ecuador with ash during March and April, 1926.



Fig. 10 – (Left) Cataract on right bank of the Coca River about 59 miles above the mouth. Total fall over 1300 feet.



Fig. 11 – (Right) View of one of the twin falls of the Coca River 60 miles from the mouth. Total fall of each is about 1500 feet.

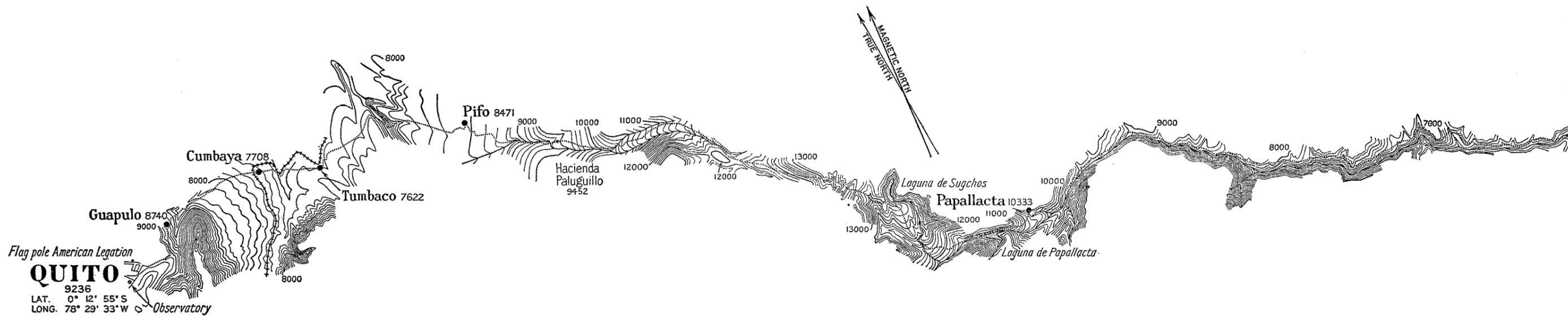
But short as was the distance to the volcano, there was a canyon between us over 2000 feet deep with cliff walls very difficult to scale and with a river about 150 feet wide in its bottom filled with rapids that could be crossed only by some sort of suspension bridge. Even if we had the materials for such an enterprise it would be necessary to carry the expedition a number of miles upstream in search of a crossing. Moreover, our Indians were without food and were becoming ill, and we were concerned about conditions at our base camp. Obviously, it was wiser to return. This decision reached, we moved back at full speed, sliding down the cliffs to the river. Half swimming in the rising waters and half cutting around the cliffs by ascending into the forest, we reached at noon on December 22 the camp ground of December 18-19. Again, the cry "El volcán". Looking due west up the river we saw the jagged peaks of "El Reventador", this time standing out clear and near in a favorable moment between the lifting and falling of the ever-present mist, too short, however, to permit the taking of a photograph.

THE RETURN JOURNEY

The 23rd of December proved the wisdom of our forced march to the base camp, for the Coca was a roaring torrent in flood. On the 24th it was still very high; but Rivadeneira and I decided that we could stay no longer and, as by a miracle, we successfully negotiated the nine miles of horrible rapids to the mouth of the Lashino. Here we bade goodbye to the Cofanes Indians. After the distribution of presents to them there was a great handshaking all around. The Napo and Payamino Indians, who had from infancy heard of the Cofanes as cannibals, parted from their newly-made friends with promises to come back to hunt and fish someday.

At the confluence with the Napo it was necessary to reorganize for the hundred miles of poling up that stream. By the 27th, however, we had secured new Indians from below the Coca, thanks to the aid of Jacinto Bejarano, and started upstream. For seven days we poled against the current an average of a little less than 15 miles a day – in itself no mean accomplishment. The arrival at Napo village called for another reorganization, for the Indians from below the mouth of the Coca could not go any farther away. Bejarano, who had pushed on ahead of us, had arranged with Señor Serrano at Archidona for another outfit of Indians; but we had to wait till January 6 before we could get them together. On that date we poled the canoes a mile up the Napo to the mouth of the Anzu and then another ten miles to the head of canoe navigation on this stream, where we disembarked and took to a muddy trail 36 miles across the forests to the Pastaza, which we had surveyed in 1921.

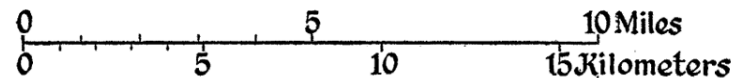
On January 11 we arrived at the village of Mera on the latter stream, a point 3800 feet above the sea where the Pastaza emerges from its great canyon in the Andes onto the Amazon lowlands. This route from the Napo was resurveyed shortly after our 1921 traverse by an American oil company, for the purpose of constructing an automobile highway to Napo from the head of the Pastaza Valley. The proposed highway was to leave the Curaray Railway at Pelileo, 21 miles from Ambato, proceed about ten miles to Baños, 6014 feet above the sea, and then descend the Pastaza Valley 27 miles to Mera, where it was to continue overland 48 miles to the village of Napo, descending the Anzu to the Napo. By January, 1928, this road had been constructed from Pelileo to within two miles of Baños, but it was partially destroyed in February by a great landslide on the slopes of the mountain Carihuarizo which let loose into the Pastaza Valley an enormous amount of water and mud. On January 12 we obtained horses at Mera for ourselves, retaining the Indians to pack our outfit to Baños. We arrived in Ambato on the evening of January 14 and on the 15th proceeded to Quito.



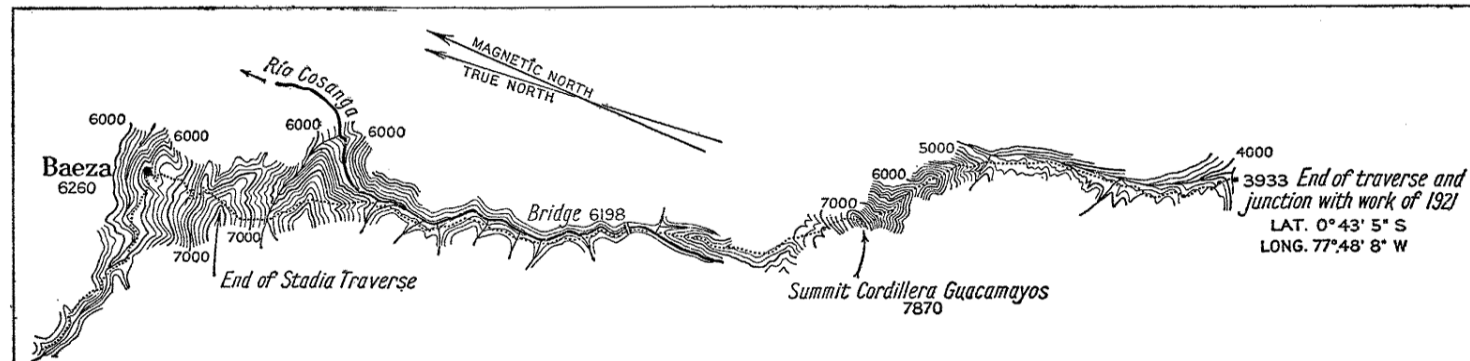
STADIA AND PLANE TABLE TRAVERSE OF THE PAPALLACTA TRAIL

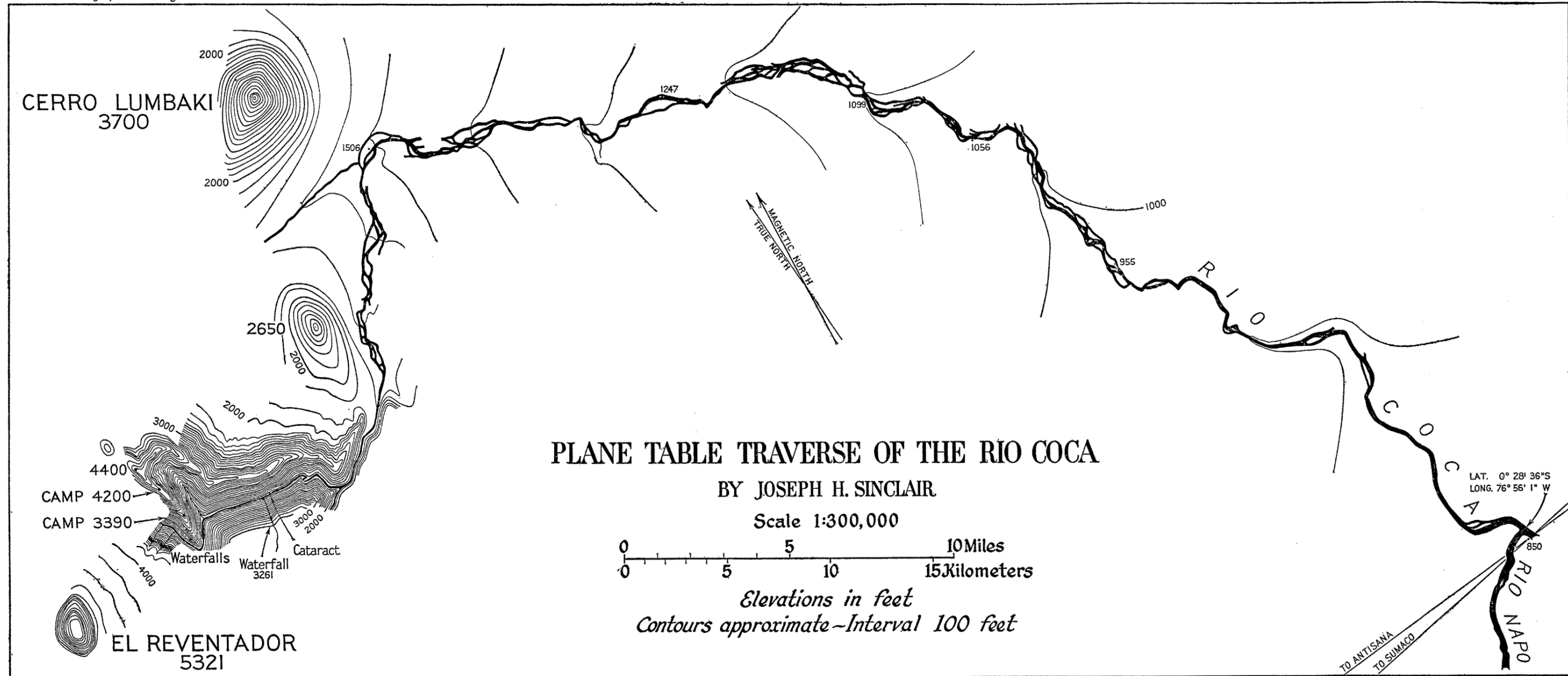
BY JOSEPH H. SINCLAIR

Scale 1:300,000



Elevations in feet
Contours approximate—Interval 100 feet





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**METAMORPHIC AND
IGNEOUS ROCKS
OF EASTERN ECUADOR¹**

by

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and

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I. INTRODUCTION

The rocks, from Eastern Ecuador, described in the following pages were collected during two exceedingly difficult journeys, one in 1921(5)¹ and the other in 1927-1928 (4), in that part of eastern Ecuador called the "Oriente", lying between the Equator and 2°S Latitude, and extending from the culminating peaks of the Andes Mountains as far east as the confluence of the Napo and Coca Rivers, 77° west of Greenwich.

The geological results of the first expedition were published in part as a memoir (7), which was limited almost entirely to a description of the sedimentary rocks and their fossils, the latter proving the presence in eastern Ecuador of sediments as old as the Albian subdivision of the Cretaceous period.

Considerable petrographic work has been done on rocks from the Andes of Ecuador, but practically none on those from the "Oriente" or forested foothills and lowlands east of the Andes. The volcanic mountains of the lofty Andes, such as Chimborazo, Cotopaxi, etc., have been a favorite field of study for European geologists and the results of their investigations are set forth in so many papers that we cannot attempt to cite them all.

The German geologists, Wilhelm Reiss and Alphons Stübel, (3) may be single out for mention because of their labors, extending over a period of five years, during which all parts of the Andes of Ecuador were visited. They made collections of the different rocks encountered and submitted them to German petrographers for study. In the course of their investigations, they collected material from three localities on the western boundary of the area we are describing.

Reiss and Stübel worked in Ecuador from 1870 to 1874; in this period, they collected about 6000 specimens of igneous rocks. For the petrographic studies of these rocks over 1800 thin sections were examined by various petrographers. Even the bibliography pertaining to the work of Reiss and Stübel and their collaborators is too lengthy to be cited in this memoir.

Previous to the 1921 expedition of Sinclair and Wasson no pre-Tertiary fossils had ever been found in Ecuador. It was concluded, merely on the basis of similar rocks elsewhere, that the few outcrops of sedimentary rocks found here and there, in very disturbed conditions in the midst of igneous rocks, were of Cretaceous age. The Igneous rocks of the Andean highlands of Ecuador have, however, been described as Tertiary and Quaternary lavas, and the metamorphic rocks, consisting of schists and gneisses, are thought by all geologists who have made field studies of them, to be very ancient.

The best description of the igneous rocks nearest our area is that of Von Wolff, (2) who gives in great detail the results of his petrographic examination of the Reiss and Stübel collection from the peaks of the Andes along the western border of our area.

¹ Throughout the present paper italicized number enclosed in parentheses refer to references similarly designated in the bibliography.

The value of our collections from eastern Ecuador lies not only in the number of specimens and variety of igneous rocks represented, but in the fact that in this area, for the first time, the field relations between sediments of proven age, and a large series of altered volcanic rocks, were clearly seen. In the "Oriente" the Cretaceous sediments occur over wide areas in a nearly horizontal attitude and at times their lower beds may be seen underlain by certain of the igneous rocks. In the Andes it is impossible to tell whether the igneous rocks lie above or below the few sediments exposed.

The expeditions of 1921 and 1927 proved that volcanoes, hitherto thought to be limited to the high Andes, are likewise present in the foothills and lowlands far to the east. The great volcano "Sumaco" lifts its mighty cone in the midst of the Cretaceous rocks of the foothills. In 1926 a new and hitherto unknown volcano, called by the Indians "El Reventador", came into activity at a point about 30 miles east of the main Andes, and it is possible that other volcanic centers may be discovered later.

With the exception of several specimens of recent lavas collected from lava streams which have flowed down the slopes of Antisana to the Oriente, and from other localities which may represent isolated outflows of lavas, no other specimens of *recent* lavas were collected by the expeditions of 1921 and 1927, because these are so widely distributed in the Andes immediately to the west and because they have been previously described.

The only specimens of recent lavas from *eastern* Ecuador previously described in geological literature (*1*), proved to be unique in that they are the first feldspathoid lavas so far known in all of Ecuador.

II. PHYSIOGRAPHIC FEATURES

The region from which the collections were made is intermediate between the lofty summits of the Andes and the low-lying Amazon plain. On the west are the great snow and glacier-capped peaks of Cayambe (19000 feet), Antisana (18700 feet), Cotopaxi (19300 feet), Tungurahua (16500 feet), El Altar (17400 feet) and Sangay (17100 feet). On the east, at the confluence of the Napo and Coca Rivers, and only ninety miles from the above line of summits, elevations as low as 850 feet above the sea are found. This general slope is interrupted by minor mountain masses, themselves of great elevation and prominence. The gigantic volcanic cone of Sumaco, for example, rears itself to an elevation of 12500 feet half-way between Antisana and the confluence of the Napo and Coca Rivers. The still unexplored Galeras Mountains, twenty-eight miles south of Sumaco, have summits about 5400 feet above sea level and the volcano "El Reventador", recently become active and situated about forty-five miles north of Sumaco, is a prominent mass about 6000 feet above sea level. Thus, the area is one of strong topographic features.

The rivers descend from the snow-covered summits of the Equator in profound gorges, leaping in places down great cataracts and reaching the "fall line", in almost continuous rapids, at about 850 feet elevation.

III. DIFFICULTIES OF EXPLORATION

The difficulties of exploring this region are made almost insurmountable by the excessive rainfall which, in places, attains seventeen feet per annum, and by forests which cover the entire area up to an elevation of about 10000 feet above the sea. In these forests the few footpaths are but gloomy tunnels through the vegetation, where the traveler wallows knee-deep in mud and is subjected to a constant downpour from rain and from the dripping trees. The temperature and climatic conditions vary from the tropical heat prevalent at the mouth of the Coca to the snow storms of the high passes, which have an elevation of 13000 feet. The population is exceedingly limited. Dwellings of Indians are found at very rare intervals and the occasional widely separated villages of the white pioneers have very few inhabitants.

IV. PETROGRAPHY

The forty-four samples of rocks described in the following pages, collected east of the Andes during the two expeditions of 1921 and 1927, may be divided into five groups:

- A. Metamorphic rocks: schists of various types.
- B. Igneous rocks: chiefly surface types, of proven pre-Albian age.
- C. Igneous rocks: chiefly surface types, probably also pre-Albian, but whose age is not certain because their outcrops are distant from occurrences of sediments of known geologic horizon.
- D. Granites.
- E. Lavas of late Tertiary, Quaternary and Recent age.

The name of each rock and the group to which it belongs on the basis of the above classification are shown in Table I.

The igneous rocks, excepting the granites and schists, might be subdivided into two sub-groups, (1) surface flows and tuffs, of unquestioned pre-Tertiary age because of the profoundly altered condition of the rocks; and (2) volcanic rocks of Tertiary to Recent age, because of the lack of alteration of any of the primary minerals.

A. METAMORPHIC ROCKS

The Schists

The "core" of the Andes of Ecuador consists of metamorphic rocks, schists and gneisses, of unknown age, although they are generally considered pre-Paleozoic and are judged to be a part of the wide-spread formation of the same character common in many parts of South America.

In Ecuador these schists and gneisses outcrop from the Peruvian to the Colombian borders in an almost continuous, narrow band, running nearly north and south like the main Andean cordillera. The line of lofty volcanic peaks forming the Eastern boundary of the high Andes and the eastern slopes of these mountains down to what may be called the base of the Andes are included in this area.

The schists are exposed at elevations as high as 13448 feet² above the sea in this belt in Ecuador. In the western part of the Andes, they are generally concealed beneath enormous masses of lavas and tuffs, the products of Tertiary and recent volcanic action. It is fairly logical to conclude that these schists are the oldest rocks of Ecuador. The peculiar narrowness of their outcrop suggests that they form the exposed base and sides of a great fault-block which is tilted westward toward the Pacific Ocean.

The schists described in this memoir were collected from the Papallacta gorge, one of the great gorges which cut into the eastern slope of the Andes, in which waters of the Río Papallacta and the Río Quijos unite to form the Río Coca. They were first encountered at an elevation of 9400 feet; proceeding eastward down the gorge they disappear at an elevation of 6400 feet. They thus outcrop in a vertical range of 3000 feet. The width of this belt in the Papallacta gorge is about fourteen miles. At the upper boundary in the vicinity of the village of Papallacta they vanish beneath late Tertiary lavas and tuffs and do not reappear anywhere in the thirty-three miles between this point and Quito, although during the traverse we ascended to over 13000 feet above the sea and descended as low as 7400 feet.

The nine samples collected in the above-named gorge are intensely metamorphosed rocks. They are all crystalline schists, folded, crumpled, and presenting all the aspects of rock that has been subjected to regional dynamic metamorphism in conjunction with attack from a subjacent igneous source. They present an exceedingly complex history involving an origin that in some cases was certainly igneous, in others probably sedimentary.

Since there are some interesting features connected with the samples, they are here described in detail. Furthermore, with the exception of the three samples collected by Reiss and Stübel in August 1871³, no description has been published of these Papallacta Valley schists.

- *Specimen No. 1* was collected from a massive outcrop 2.5 miles east of the hamlet of Papallacta, on the left bank on the river along the trail at an elevation of 9404 feet.

It is a light gray rock with variable texture, carrying much glistening scaly sericite; it is very streaked and heterogenous in make-up, coarse, foliated and strongly sheared, with the general aspect of a schist.

Petrographically the rock proves to have been initially igneous in origin: either a granite or granodiorite. The original character is considerably obscured by shearing and by reason of the changes brought about through the modification of the former components by the attack of igneous matters. There is, therefore, an antecedent structure within the rock, inherited from a former condition, and in addition secondary structures imposed upon it as well. The original minerals consisted largely of hypidiomorphic plagioclase feldspars, biotite, and perhaps quartz, although it is uncertain how much of the quartz was present initially as primary orthotectic quartz and how much invaded the rock during the later metamorphic stage

² Feldspar-rich mica schists somewhat phyllitic, from the west summit of Jacatuna de Numuloma western foothills of Antisana, according to Reiss and Stübel.

³ The collection of Reiss and Stübel consists of a "phyllite gneiss" from the church at the village of Papallacta, boulders of phyllite gneiss in the Río Papallacta at the mouth of the Yurac-yacu and a "muscovite mica schist" carrying abundant carbonaceous matter from the Papallacta valley between the hamlet of Papallacta and the mouth of Yurac-yacu.

TABLE I

		Locality	Sample No.	Name of Rock
METAMORPHIC	SCHISTS	Río Papallacta	1	Orthoschist of complex origin
		Río Papallacta	2a	Orthoschist of complex origin
		Río Papallacta	1a	Quartz sericite schist
		Río Papallacta	3	Sheared rock; mylonitized
		Río Papallacta	4	Helicitic mica schist
		Río Papallacta	5	Sismondite schist
		Río Papallacta	5a	Sheared meta-diorite porphyry
		Río Papallacta	6	Sheared meta-diorite porphyry
		Río Papallacta	6a	Sheared meta-diorite porphyry
		Río Papallacta	7	Orthoschist (Greenstone schist)
		Río Quijos	8	Biotitic schist of complex origin
		Río Quijos	9	Schistose rock of complex origin
IGNEOUS	(a) PRE-ALBIAN (PRE-MIDDLE CRETACEOUS) VOLCANICS	Río Coca	1L	Devitrified acid volcanic tuff
		Río Coca	L-a	Devitrified volcanic ash
		Río Coca	Z	Meta-andesite
		Río Coca	1	Trachy-andesite or latite
		Río Coca	1-a	Latite tuff or tuffaceous latite
		Río Coca	2	Acid volcanic tuff
		Río Coca	3	Spherulitic felsite
		Río Coca	4	Volcanic tuff
		Río Coca	5	Modified basalt
		Río Coca	6	Andesitic tuff
		Río Coca	17	Basaltic andesite
		Río Coca	18	Porphyritic latite
		Río Misahuallí	A	Tuffaceous trachytic felsophyre or modified trachytic ash
		Río Misahuallí	69	Trachytic felsophyre
		Río Misahuallí	71	Altered basaltic amygdaloid
		Río Misahuallí	72	Altered basalt
		Río Misahuallí	72-c	Altered amygdaloidal basalt
		Río Misahuallí	73	Dellenitic tuff
		Río Jandache	B	Dellenitic vitrophyre
	(b) PROBABLE PRE-ALBIAN VOLCANICS. Excepting Nos. 11 and 12.	Río Pastaza	7a	Rhyolite
		Río Pastaza	7c	Rhyolite
		Guacamayos Mt.	A	Weathered monzonite porphyry
		Guacamayos Mt.	B	Spherulitic granophyre
		Guacamayos Mt.	C	Gabbro, much altered
		Río Papallacta	2b	Silicified, kaolinized andesite. Included here for convenience
		Río Quijos	12	Serpentinized rock
		Río Quijos	11	Limestone breccia
	(c) GRANITES	Río Urcusikiyacu	a	Biotite granite
		Río Napo	b	Biotite granite
		Río Pastaza	7b	Graphic granite
	(d) QUATERNARY LAVAS	Río Papallacta	10	Basalt
		Río Cosanga	2	Andesite

The plagioclase is fracture and microfaulted; the older plagioclase is almost wholly, if not entirely, replaced and modified so that only the “ghosts” of it remain. The modification products consist of little prisms of zoisite, grains of epidote, shreds of sericite, little grains of garnet, some of them quite idiomorphic, and turbid patches composed of a very minutely granular aggregates of the same set of products just mentioned, that correspond to saussurite. All of these products are confined within the limits of what was the original plagioclase; they are now included in new crystals of albite that extend beyond the limits of the older plagioclase and which have largely replaced the older feldspar. In places the albitized plagioclase has taken on a “pseudo-perthitic” structure due to deformation, subsequent to the period of replacement, that ruptured and displaced the albite twinning so that the feldspar, at first glance, resembles microperthite. Only the merest traces of the structure and the substance of the earlier plagioclase are preserved, but the *forms* of the older plagioclase are in places emphasized by the groups of alteration products just referred to.

The biotite seldom retains any semblance of its original form; it is commonly squeezed out into streaks composed of fine shreds and minute flakes of colorless mica mixed with yellowish-white opaque specks of leucoxene, specks of iron-oxide and grains of quartz. There are a few remnants that still retain some suggestion of their original shapes, but even these are bent and distorted, and all of them are altered in the manner described.



FIG. 1 – *Papallacta No. 1* – Orthoschist of complex origin. Drawing, ordinary light, showing relics of older feldspar in later albite. The older feldspar consists of aggregates of zoisite-epidote-sericite, garnet grains, and minutely granular aggregates of the same set of products. Colorless areas are quartz with inclusion trains. $\times 43$

The later albite is filled with both crystal and bubble and liquid inclusions, roughly oriented, and commonly intersecting the cleavage directions at an oblique angle.

Quartz, albite and a little muscovite were introduced into the rock during the later stages of its metamorphism, transecting fractured feldspars and distributed in streaks and patches. Even the later quartz and albite that were introduced and whose feldspar has in part replaced the older feldspar of the rock, have been deformed by fracturing and granulation, so that at least two stages of deformation are recorded; one was connected with the period of “soaking” by granites juices that effected replacement of earlier feldspars and the “granitization” of the rock; the other, and later, post-granitization period of deformation granulated and fractured both the granitized rock and the replacement matter. In addition, there is evidence that the introduction of quartz continued subsequent to the later deformation, since in both No. 1 and No. 2a there are areas of quartz and associated calcite in granular mosaic aggregates that exhibit no signs of deformation at all.

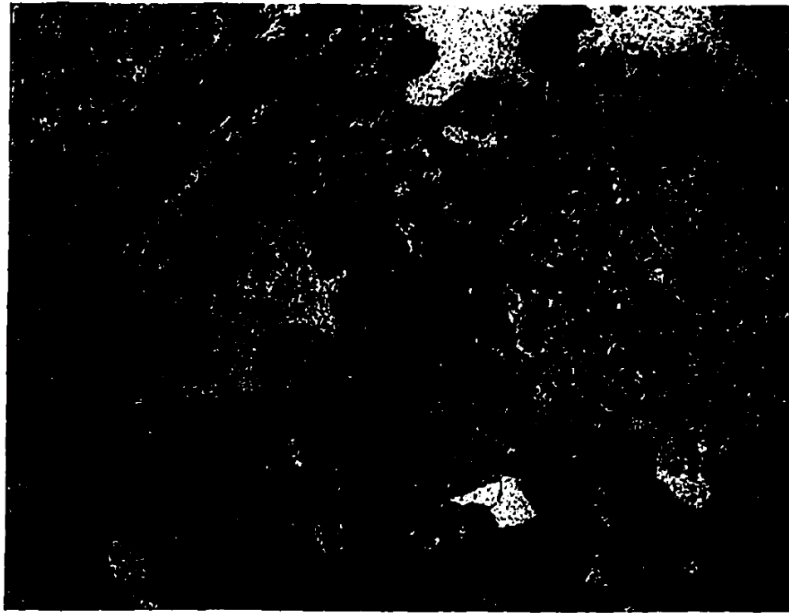


FIG. 2 – *Papallacta No. 1* – Photomicrograph of the same schist shown in Figure 1, nicols crossed. Note the relic structures of older feldspar in later albite, and the granular aggregate of zoisite-epidote-sericite in the fresh albite. $\times 34$.

- ***Specimen No. 2a***, taken 6.7 miles east of Papallacta at an elevation of 8571 feet, is similar to No.1 in character, structure and history. This is a light colored, streaked and schistose, coarse textured rock. The plagioclase is fractured and crowded with innumerable inclusions consisting largely of coarse sericite, with less epidote and zoisite, garnet grains, granular titanite and chlorite. The same set of products mixed with granular quartz, albite and a little pyrrhotite, are distributed along fracture zones as well. There is considerably more calcite associated with the introduced quartz and feldspar than in Specimen No.1, but the two specimens are very much alike in other respects.

Despite the fact that these two specimens were secured from exposures four miles apart and differing in elevation eight hundred feet, they are essentially alike in composition, and the sequence of events recorded in them is the same.

Some of the features described are shown in Figure 1, which is a drawing from a thin section of Specimen No.1, and in Figure 2, a photomicrograph of Specimen No.1, taken with nicols crossed. The drawing, which represents the appearance of the section in ordinary light, shows the older plagioclase crowded with very fine, dense aggregates of epidote-zoisite, mixed with larger grains and prisms of the same minerals, in an albite matrix that extends in clear areas beyond the original margins of the older plagioclase.

The photomicrograph (Fig. 2), taken at a lower magnification than the drawing (Fig. 1), illustrates the same set of conditions. Although there is little suggestion of schistosity in either the drawing or in the photomicrograph the rock itself is not only coarsely foliated but exhibits injection effects as well. It is clearly an orthoschist, but it has an added complexity due to soaking, injection and resultant modification and replacement brought about either by an attack of the end-stage concentration-residua of the same magma that gave birth to the granodiorite or to an attack by a later magma.

TABLE II: TABLE OF ANALYSES

		1	2	3	4	5	6	7	8	9
Silica	SiO ₂	67.54	67.18	59.47	66.10	65.30	60.42	60.50	56.76	63.40
Alumina	Al ₂ O ₃	15.26	15.45	16.52	15.32	18.02	16.32	18.20	16.20	16.57
Ferric Oxide	Fe ₂ O ₃	1.29	1.75	2.63	1.97	1.17	1.93	4.52	4.16	1.90
Ferrous Oxide	FeO	2.82	2.27	4.11	2.90	4.71	2.62	0.86	3.36	1.90
Magnesia	MgO	2.85	1.55	3.75	1.77	2.87	3.82	2.87	4.08	2.14
Lime	CaO	2.16	3.57	6.24	3.81	0.98	5.06	2.39	5.82	3.83
Soda	Na ₂ O	4.94	3.63	2.98	3.48	1.12	4.41	4.63	3.93	4.77
Potassa	K ₂ O	0.92	2.79	1.93	2.74	2.47	0.65	1.90	2.39	3.48
Water 110°	H ₂ O -	0.04	-	1.39	1.06	0.00	0.01	0.59	-	-
Water over 110°	H ₂ O +	0.81	-	-	-	1.93	0.90	1.96	-	-
Titanium Oxide	TiO ₂	0.68	0.50	0.64	0.53	0.50	0.58	0.74	0.96	0.48
Phos-Pentaoxide	P ₂ O ₅	0.10	0.23	0.26	0.27	0.10	0.10	0.10	0.25	0.21
Manganous Oxide	MnO	0.28	0.21	0.08	0.04	0.39	0.47	0.80	0.12	0.07
Sulphur tri-oxide	SO ₃	0.07	-	-	-	0.03	0.09	0.09	-	-
Carbon dioxide	CO ₂	0.04	-	-	-	0.29	1.72	0.03	-	-
						Iron (as Fe) Sulphur as S)	0.37 0.21			
TOTAL		99.8	99.13	100.00	99.99	99.88	99.68	100.18	98.03	98.75

1. Sample No. 1. Papallacta. Analysis by Ledoux & Co., New York
2. Average of 10 analyses of granodiorites
3. Average of 20 analyses of quartz-diorites. Daly, R. A., *Igneous Rocks and Their Origin* [Las Rocas Ígneas y su Origen], 1914, p. 26.
4. Average of 37 analyses of tonalite, quartz monzonite, granodiorite. Daly, R. A., *Idem*, p. 25.
5. Sample No. 5, Papallacta. Analysis by Ledoux & Co., New York
6. Sample No. 6, Papallacta. Analysis by Ledoux & Co., New York. *Note:* This sample contains pyrite and traces of galena.
7. Sample No.6, Río Coca. Analysis by Ledoux & Co., New York
8. Average of 12 analyses of andesites. Bul. 419, U.S.G.S., 1910.
9. Average of 6 analyses of diorite porphyry. Bul. 419, U.S.G.S., 1910.

Comment on Analysis: An analysis of the rock, compared with averaged analyses of 10 granodiorites, 20 quartz-diorites, and a combined average of 37 analyses of tonalite, quartz-monzonite and granodiorite, shows marked differences in the proportions of certain of the constituents, more especially when the analysis of Papallacta No. 1 is compared with the average for granodiorite.

The average granodiorites (Nos. 2 and 4, Table of Analyses) carry three times as much potash as sample No.1 from the Papallacta trail, but only two-thirds as much soda. The lime is higher in the average granodiorites, but the magnesia is considerably lower. The percentages of silica and alumina, however, in the averaged analyses of granodiorites, are nearly equal to the silica and alumina in sample No.1, Papallacta. The analysis of the Papallacta rock is not at all comparable with the average of twenty analyses of quartz-diorites, which is included here merely for the purpose of extending the range of comparison. These differences in the composition of the Papallacta rock, compared with the composition of average granodiorite, may be due in part to the entrance of igneous emanations from a subjacent source, and the replacement of feldspar, originally richer in potash, by soda-rich emanations. While the rock, judging merely from the thin section, is a sheared and modified granodiorite, it is probable that this particular specimen happened to contain more of the granodiorite material than of the older schist invaded by the granodiorite, so that there are but traces of the older schist in this sample.

- **Specimen No. 1a**, 2.5 miles east of Papallacta, elevation 9404 feet, is a moderately fine textured *quartz-sericite schist* of uncertain initial origin. Although the sample was secured in the same place as No.1, there is but little resemblance between them except in the matter of certain minerals that are common to both. The rock consists of quartz, prisms of zoisite and epidote, streaks and plates of chlorite and muscovite, a little blue-green amphibole, clear untwinned feldspar of lower index than balsam ($< 1.535 \pm$) and with extinction angles measured from cleavages that range from 10° to 30° , a most unusual feature; granular titanite, crystals of zircon and a little pyrrhotite, all oriented in the plane of schistosity of the rock. The streaks and plates of muscovite and chlorite, the little prisms of epidote, zoisite and blue-green amphibole and some of the quartz that is elongated in the plane of schistosity, are responsible for the schistose structure. But there are streaks of quartz and feldspar that are quite granular and mosaic-like and which impart no schistosity to the rock at all. These have the character of injected matter derived from an igneous source; that is, these streaks are judged to be *lit-par-lit* injections of a sort.

There is no direct evidence bearing on the initial condition of the rock; it is impossible to determine whether it represents an intensely metamorphosed sediment or whether it is a strongly sheared and highly metamorphosed portion of the granodiorite, although it seems more probable that this sample represents the older schist, of sedimentary origin, rather than an intensely sheared phase of a massive rock like the granodiorite. Whatever the original condition, the rock has not only been converted into a crystalline schist, but it has also been affected by injections of matter under igneous control, a circumstance favoring the conclusion that this specimen represents some of the older schists of probable initial sedimentary origin.



FIG. 3 – *Papallacta 1a* – Quartz sericite schist. Photomicrograph, ordinary light, showing schistosity. The band in the upper half of the picture is a granular mosaic of aggregate quartz with undeformed grains. The large darker gray patches are chlorite, the small grains and prisms are epidote and zoisite, the lighter colored foils and needles are sericite. $\times 24$.

The character of this rock is shown in Figure 3, which illustrates some of the conditions described and which presents a striking contrast to Specimen No.1, Figures 1 and 2, although both samples came from the same locality.

- ***Specimen No. 3***, 7.5 miles east of Papallacta, elevation 8330 feet, is a coarse textured, brown, iron-stained, chalky-spotted, sheared rock resembling a sheared and weathered granite or granodiorite. It has been subjected to crushing of considerable intensity, so that the rock is more or less mylonitized, and much limonitic matter has developed, together with a white, opaque substance distributed in streaks that cut all the other minerals in the rock. There are uncrushed patches and streaks of coarsely granular, interlocking mosaic-aggregates of quartz, areas composed of very fine, brilliantly polarizing, flaky aggregates of colorless mica, and coarser muscovite, in aggregate groups, that is associated with alkali feldspar and that carries innumerable inclusions oriented transverse to the cleavage of the mica; under high magnification these prove to be long and narrow cavities filled with liquid and bubbles.

There is evidence indicating two stages of deformation; the earlier was the more intense. It is judged that during this stage the rock was crushed and granulated. The other and later period was productive of fractures that cut all of the other structures in the rock. Surface agencies have attacked the rock along these later weaknesses with the production of limonitic matters.

While the initial character of the rock is very obscure, it is probably an extensively sheared phase of the granodiorite.

- *Specimen No. 4*, 9 miles east of Papallacta, elevation 8114 feet, is strongly schistose, folded and crumpled, black and white laminated, and very micaceous. It has all the aspects of a soaked, injected, silvery mica schist.

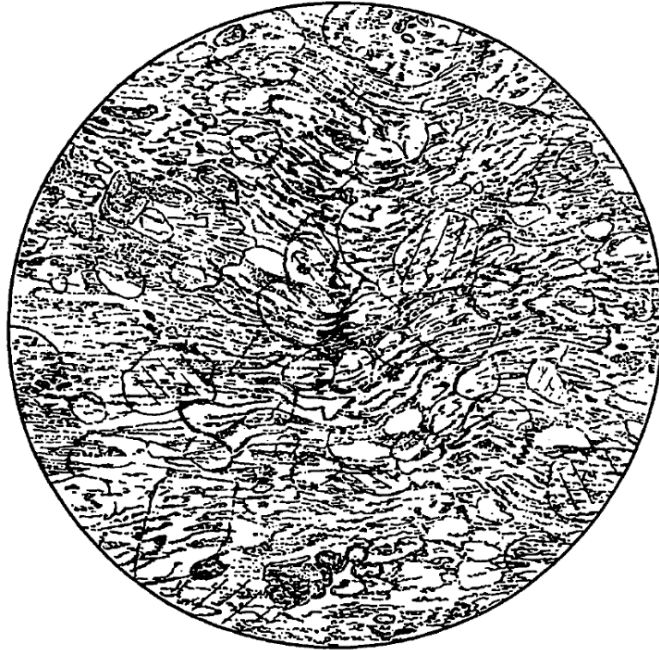


FIG. 4 – *Papallacta* No. 4 – Helicitic mica schist. Drawing, ordinary light, showing helicitic structure. The relic schist structure, now preserved in the form of carbonaceous dots and streaks, passes through the later replacing quartz and feldspar, which of itself is not schistose at all. $\times 24.2$.

In thin section it exhibits an extremely striking helicitic structure, by reason of the replacement of the body of the schist with granular quartz and an optically positive feldspar that is occasionally twinned after the Carlsbad law, whose indices of refraction are lower than the index of the balsam, and with extinction angles as high as 25° measured from well-developed cleavage; a feature similar to that mentioned as occurring in Specimen No. 1a.

The crystals of feldspar are allotriomorphic to hypidiomorphic, very rarely exhibiting albite twinning. They are metapoikilitic carrying many inclusions consisting of minute blebs of quartz, many small prisms of zoisite, grains of zircon, little tourmaline crystals, epidote grains, titanite grains, prisms of apatite, and considerable fine, black and possibly carbonaceous or graphitic matter, all distributed in a crumpled, schistose structure that passes indifferently through the grains and the boundaries of the grains of the replacing quartz and feldspar, as well as through crystals of muscovite that is associated with the quartz and feldspar. These “ghosts” of schistosity serve to emphasize the relic structure in the schist.

There are also bands of clear aggregate quartz, likewise mixed with feldspar and with a very faintly green, beautifully twinned clinocllore.

The specimen shows more or less clearly:

- The development of a schist from an unknown, but probably sedimentary, original, by metamorphic processes of considerable intensity. The schist may have been initially a phyllite derived from a sediment, somewhat crumpled, and perhaps somewhat graphitic.

(b) Soaking, injection and actual replacement by end-stage concentration residua from a granitic or granodioritic source; much of the quartz and all of the feldspar belong to this stage and it is probable that the clinochlore and muscovite are products formed by the action of the emanation-residua on the matter composing the original schist.

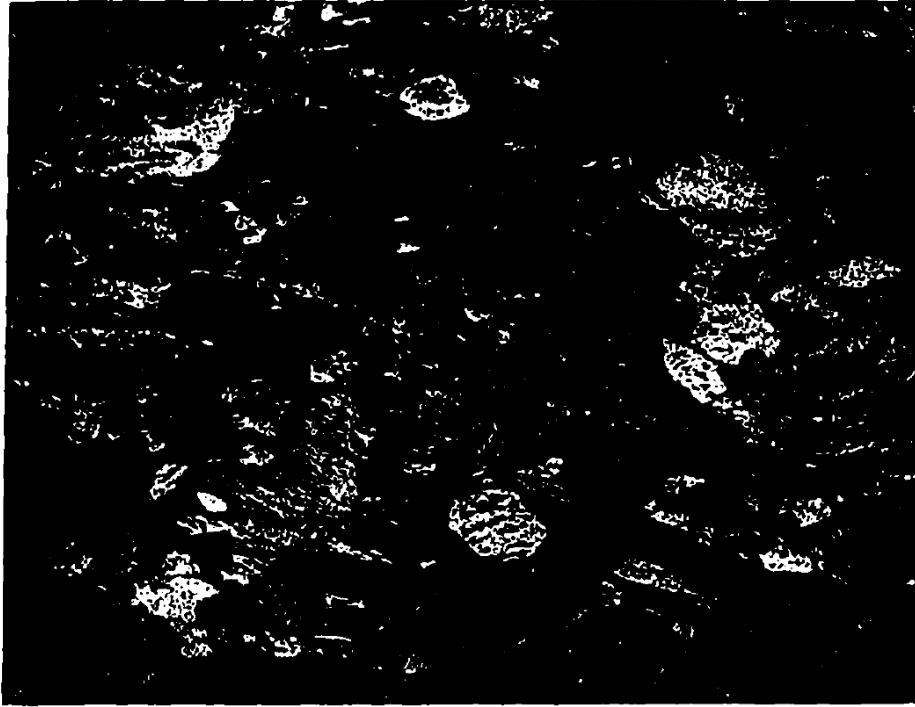


FIG. 5 – *Papallacta* No. 4 – Photomicrograph of the same schist shown in Figure 4, nicols crossed. Note the granular aggregates of undeformed quartz and albite, replacing the substance of the rock, and containing ghost structures of the original phyllite. $\times 24$.

This very striking rock, with its beautiful helicitic structure and clearly indicated history of the replacement of an original phyllite by emanations from a magmatic source, is illustrated by Figure 4, drawing made in ordinary light, showing the relic structure of the schist passing indifferently through the replacement-mosaic of quartz and feldspar; and by Figure 5, a photomicrograph taken at a lower magnification than that represented by the drawing, showing the aspect of the section between crossed nicols.



FIG. 6 – *Papallacta No.5* – Sismondite schist. Drawing, ordinary light, showing rosettes, grains and prismoids of ottrelite (sismondite). The colorless portions are quartz. Schistosity due to arrangements of sismondite also shown. $\times 43$.

- **Specimen No. 5**, 10.1 miles east of Papallacta, elevation 7579 feet, is a fine texture, silvery gray, *muscovitic schist*, composed of quartz elongated in the plane of schistosity, long sinuous streaks of muscovite that at times enclose microscopic augen composed of compound grains of quartz, and prisms, bundles, groups and rosettes of a colorless variety of chloritoid corresponding to sismondite. The rosettes are formed of prismoids radiating from centers that consist of unit and compound quartz grains filled with minute included grains of sismondite. The prisms exhibit polysynthetic twinning, a common characteristic of ottrelite; the lack of both color and pleochroism suggests, however, that the crystals carry more magnesia and much less iron than ordinary ottrelite. The analysis of the rock supports this statement; most of the magnesia reported in the analysis is probably contained in the sismondite, since the only other essential components in the rock are muscovite and quartz. There are minutely microscopic crystals of rutile sparsely disseminated in the rock, many exhibiting geniculate twinning on a microscopic scale. Provided the greater part of the magnesia is contained in the sismondite, the rock should carry almost 15% of that component. This corresponds approximately with the mineral composition exhibited by the section.

Comment of Analysis: The alumina (18.02%) is higher in proportion to the silica (65.03%) than is normal for a rock carrying the amount of combined alkalis ($K_2O + Na_2O = 3.59\%$) that this one does, and the lime (0.98%) is relatively low (see Table of Analyses), assuming the schist to have been derived from an igneous rock. The potash and soda are probably contained for the most part in the muscovite, although some of the soda may be in the sismondite. The iron is probably distributed in large part in both the muscovite and sismondite.

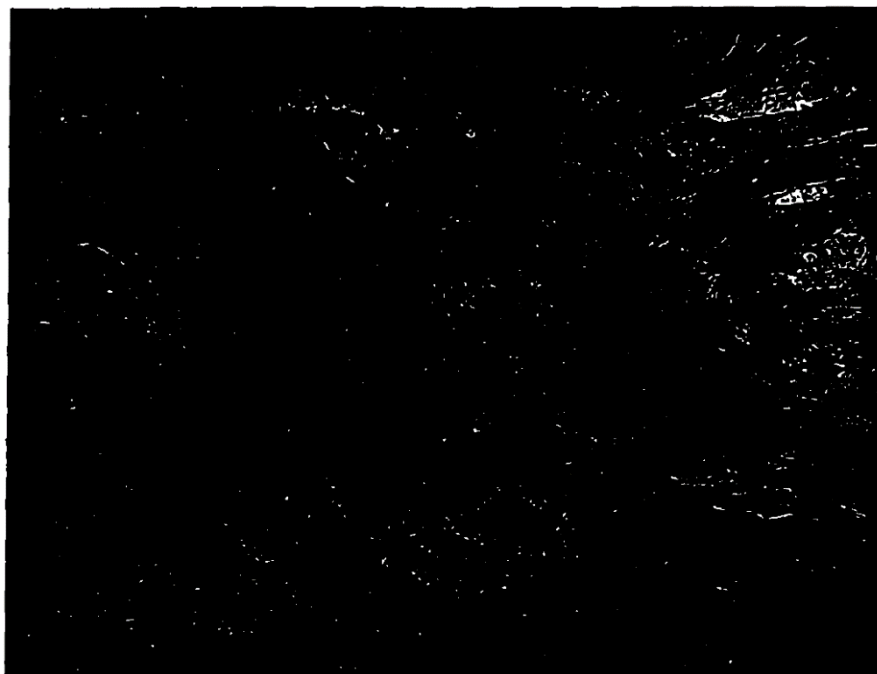


FIG. 7 – *Papallacta No. 5* – Photomicrograph of the same schist shown in Figure 6, ordinary light. Rough, high relief prisms and grains are sismondite. The lower relief streaks are muscovite, the plain, smooth areas are quartz. $\times 33$.

From the chemical composition and mineralogical make-up of the rock, it is judged that this quartz-muscovite-sismondite schist was derived by intense dynamic metamorphism from a former sediment, rather than from an igneous rock.

The character of the rock is illustrated by Figure 6, drawn from the thin section in ordinary light, and by Figure 7, a photomicrograph taken in ordinary light. Some of the prismoids and rosettes of sismondite, the muscovite and quartz, and the general schistose habit of the rock, are shown.

- *Specimens Nos. 5a, 6 and 6a* are much alike. No. 5a was secured in the same locality as the sismondite schist No. 5, just described, 10 miles east of Papallacta. Nos 6 and 6a came from a locality 10.7 miles east of Papallacta, at an elevation of 7561 feet.

All of these rocks are intensely sheared and thoroughly metamorphosed porphyries that were probably initially dioritic in composition. In No. 5a the original phenocrysts of plagioclase feldspars now consist of finely granular aggregates of zoisite, epidote and albite, a little calcite and occasionally a little quartz and chlorite. Much finely granular epidote is also distributed through the groundmass, which has been entirely recrystallized into a crudely oriented, interlocking, crystalline aggregate of granular quartz, albite, garnet grains, calcite, and shreds, streaks, patches and corroded crystals of biotite. Many of the albitized phenocrysts show partial replacement by epidote and zoisite and more or less granulation along their margins; in a few instances they have been subjected to much more extensive granulation. These rocks are intensely sheared, epidotized, albitized (saussuritized), modified and reorganized metadiorite porphyries.

The groundmass of Samples No. 6 and 6a is a recrystallization and modification complex of quartz, albite, epidote, calcite, muscovite, clinochlore, and a little pyrite and pyrrhotite.

The saussurite pseudomorphs after the plagioclase phenocrysts act as augen of a sort, since the groundmass minerals swing around them in lines of dynamic flowage. In Nos. 6 and 6a the same set of conditions prevails but most of the original feldspar phenocrysts are albitized and not so thoroughly saussuritized as those in Specimen No. 5a. others have been partly, and some wholly, converted into coarsely crystalline aggregates of epidote. Corroded brown hornblende crystals are sparingly distributed in the groundmass, as well as ragged patches and streaks of clinocllore.

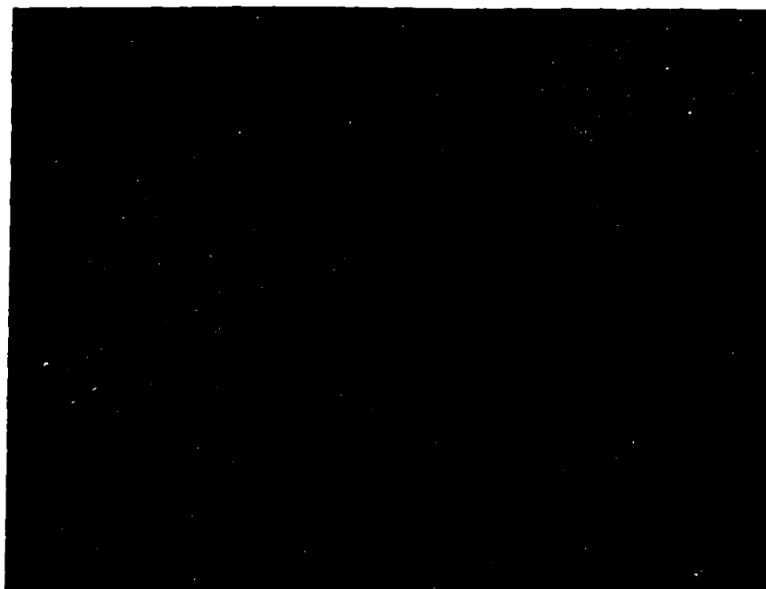


FIG. 8 – *Papallacta No. 5a* – Sheared and modified metadiorite porphyry. Photomicrograph, ordinary light. The black crystals are pseudomorphs of finely granular saussurite (extremely finely granular aggregates of zoisite-epidote-albite) after feldspar phenocrysts. The groundmass is composed of granular quartz and feldspar and little biotite crystals which are filled with minute bubble inclusions. $\times 24$.

Some of the features mentioned are shown in Figure 8, a photomicrograph of Sample No. 5a, taken in ordinary light. The black patches are minutely granular saussuritic aggregates pseudomorphs after original plagioclase phenocrysts. The completely recrystallized and modified groundmass consists largely of quartz, albite, and biotite. The innumerable minute dots in the quartz and albite of the groundmass are bubble and liquid inclusions.

Comment on Analysis: An analysis of Sample No.6 is given in the table of analyses, and for comparison the average of six analyses of diorite porphyry is likewise included.

The silica in Papallacta No.6 is lower than the average of the diorite porphyries, but all the other constituents with the exception of potash and manganous oxide are in reasonable agreement, although both magnesia and lime are higher in the Papallacta rock. There is less than one-fifth as much potash and almost seven times as much manganous oxide in Papallacta No. 6 as shown by the averaged analyses of diorite porphyry. Among the superior analyses of igneous rocks listed by Washington (6), in only two of twenty-three analysis of diorite porphyry cited is the potash less than one per cent., and in but one analysis is less than three per cent. of soda reported.

The average potash content of the twenty-three analysis is 2.52%, the average soda content 4.14%, figures comparable with the averaged alkali content of the six diorite porphyries listed in the table of analyses.

Excepting the low potash content, the composition of Sample No.6 Papallacta is comparable with the compositions of diorite porphyries the world over, so that the shearing and metamorphism of the rock may have resulted in the development of schistosity and in recrystallization of the primary substances without the addition of any other constituent and without the subtraction of any material from the rock, unless some of the potash originally present was eliminated during metamorphism, and a little soda, and perhaps water, added.

- **Sample No. 7**, 12.5 miles east of Papallacta, elevation of 6972 feet, is quite different from the preceding specimens. It is a fine, schistose, indurated green rock. The color of the rock is due to abundant, emerald green, strongly pleochroic plates of lamellar clinocllore, oriented in the plane of schistosity. Both epidote and zoisite in grains, prisms and aggregate masses are likewise abundant, and the rock contains much granular quartz and alkali feldspar, some in the form of albite, some as allotriomorphic, untwinned grains. Quartz, feldspar, clinocllore, epidote and zoisite make up nearly the whole of the rock. There is a little colorless mica occasionally intergrown with the clinocllore, and there are bands of mosaic quartz, parallel to the schistose structure of the rock, that have the aspect of later, or injection, quartz. The initial character of the rock is very obscure, but the composition of it, as observed, in thin section, suggests derivation from an igneous rock of medium basic character, perhaps somewhat similar to the sheared, albitized and metamorphosed diorite porphyries Nos. 5a, 6 and 6a, although the large amount of chlorite and epidote, and the lack of remnants of former phenocrysts, as well as the finer texture, suggest derivation from an igneous rock such as andesite or basalt. It is essentially a greenstone schist in its present condition.

- **Specimen No.8**, 14.4 miles east of Papallacta, elevation 6600 feet, is a moderately fine textured, greenish-gray, strongly biotitic schistose rock. The schistose structure is caused by shearing and recrystallization. The biotite, but crudely oriented, is distributed in long streaks and in ragged scales, flakes and patches. It is light brownish-green in the position of maximum absorption, and almost colorless in the position of least absorption. Many of the biotite flakes carry included grains of epidote and an occasional one exhibits deep brown pleochroic haloes around minute included crystals of some sort, perhaps microscopic zircon crystals. There is a little pale green clinocllore with characteristic polysynthetic twinning, and much almost-colorless epidote and associated zoisite, in swarms of grains, in larger prismatic crystals and in groups of grains. These are very prominent minerals in the rock. There is also considerable mosaic-like quartz and a pseudoperthite similar to that mentioned as present in Specimen No. 1, consisting of former plagioclase that was albitized and sufficiently deformed during subsequent shearing of the rock to have developed interrupted and offset albite twinning that resembles at first glance a microperthitic structure. Very much less prominent accessory minerals are muscovite, random small crystals of garnet, granular titanite, and a little pyrite in sharply euhedral and undeformed crystals.

Some of the quartz is distributed in mosaic-like grains that exhibit no crush-structures whatever, acting as hosts for assemblages of epidote-zoisite grains; but there are other places in the section where both quartz and feldspar have been granulated. While the original character of the rock is obscure, the composition and mineral assemblage suggest that it may have been derived from the same granodiorite that was the source of Specimen No.1. It is a biotitic schist of uncertain origin.

- *Specimen No. 9*, 16 miles east of Papallacta, elevation 6375 feet, is a fine, streaked, silvery gray schistose rock. Local areas within the section are schistose, but there is no constancy of orientation of the grains. There are, however, shear structures of later origin that cut all the other structures in the rock, and along these weaknesses a little muscovite, prisms of zoisite, epidote, and considerable carbonate, pyrite and pyrrhotite are distributed. The sulphides must have been introduced, however, subsequent to the periods of deformation, since they cut and in part replace other minerals in the rock; they are distributed interstitially in irregular stringers, they cut through quartz, feldspar and carbonate indifferently, and they transect prisms of zoisite and epidote and fill the transverse fractures in them. The same situation prevails, in part at least, with respect to the magnetite. The calcite also encroaches on other mineral grains, although the sulphides, as previously stated, are distinctly later than it, according to the structural relations between the two minerals.

Quartz and albite are prominent minerals in the rock, both full of minute inclusions in the form of opaque (magnetite?) and transparent grains, and short, stout, but extremely minute crystals and long transparent “needles”. The feldspar is albite, nearly all of which has suffered deformation; much of it exhibits interrupted and off-set twinning and carries swarms and trains of liquid and bubble inclusions in addition to those already enumerated. Most of the “needles” resemble long, thin cavities rather than crystals. They are interrupted by cross fractures, they are irregular in width, they are terminated by rounded ends and many of them contain minute inclusions themselves which may, perhaps, be excessively small bubbles. The rock is probably a sheared portion of the granodiorite.

B. IGNEOUS ROCKS

a. Pre-Albian Volcanics

In three localities in eastern Ecuador, on the Río Coca, the Río Misahuallí and the Río Jandache, the sedimentary rocks which are only slightly inclined, are underlain by greatly altered volcanics, most of them modified tuffs. The remarkable similarity of these igneous rocks from widely separated localities, and their similar relation to the same sediments, lead us to believe that these igneous rocks are of the same age.

Fossiliferous limestones of Albian (Middle Cretaceous) age are separated from contact with these igneous rocks by only a few feet of sediments; in one place they are sandstones, in another, similar limestones. It is possible that among these beds beneath the Albian marine limestones are representatives of all or some of the Ordovician, Devonian, Carboniferous, Jurassic and Lower Cretaceous sediments that are found in Perú only a few miles to the south.

It is certain that these igneous rocks are of Pre-Albian age. It is probable that they are very much older, because they seem to be surface accumulations of lava and tuffs and not intruded igneous rocks, and were therefore deposited on a land surface which had to be depressed to permit the invasion of the sea and the accumulation of the Cretaceous marine deposits.

The thickness of these igneous rocks is unknown; we have not seen their base exposed. In each of the three localities where we studied them there was about 100 feet of them beneath the lowest beds of the sediments.

In the adjacent high Andes, there are igneous rocks of similar composition and alteration which probably belong to the same formation. Below we shall discuss the probability that the felsites, andesites, porphyries, granophyres and gabbros of the Río Pastaza, Río Papallacta and the Guacamayos mountains belong to the same series.

Río Coca Series

The twelve samples from the Río Coca were collected from massive rocks outcropping in the banks of the river at points from 56 to 61 miles above the mouth of the river and representing a surface from 1864 to 2050 feet above the sea. In the ascent of the Río Coca from its mouth for 56 miles the rocks are all sedimentary. They descend progressively to rocks of older age because of a gentle eastward inclination of the strata. At a point 56 miles from the mouth of the river the base of the sediments is underlain by igneous rocks, and as far upstream as we were able to continue, to a point about 61 miles from the mouth, these igneous rocks form the bed of the river which here occupies a deep gorge walled with cliffs of sedimentary rocks.

Since the base of the igneous rocks is not visible, we do not know how thick they are or whether other sedimentary rocks underlie them or not.

The lowest of the igneous rocks, represented by samples 1-L and L-a, at elevation ± 2100 feet above the sea and about 61 miles from the mouth of the river, are volcanic fragmentals which occur as massive outcrops without any signs of stratification that we could see. Stratigraphically above these occur the rocks represented by sample No. 18, 60.5 miles above the mouth of the river, and by sample No. 2, secured at an elevation of 2008 feet, about 59 miles above the mouth of the river.

A highly tuffaceous andesite (Specimen No. 6), from the lower falls of the Río Coca, about 58 miles from the mouth and at an elevation of about 2000 feet, is found nearer the sediments.

Above this horizon, and represented by samples 1, 1a, 2, 3, 4 and 5, collected at an elevation of 1936 feet, about 58 miles from the mouth of the river, are altered trachy-andesite or latite tuff, and acid volcanic tuff, a spherulitic felsite, a volcanic tuff of about trachy-andesite make-up and a modified basalt. At this points the rocks are very massive, slightly stratified, and jointed.

The rock immediately underlying the sediments (No. 17) is a basaltic andesite.

Since nothing has been known heretofore of the geology of the isolated region from which these samples come, brief petrographic descriptions of them may be of some interest.

- *Samples 1-L and L-a* were taken farther up the canyon of the Río Coca and from a stratigraphically lower horizon than any of the other specimens of this series. They are very fine textured, strongly indurated, rocks and slightly weathered along joint surfaces. No. 1-L is gray and carries minute crystals of pyrite distributed along the joint planes. No. L-a is dark and very fine textured, but neither of them reveals its true character megascopically, because of changes brought about by the intense hydrothermal attack to which they have been subjected.

Both of these rocks are volcanic fragmentals, but they differ somewhat in the nature of the fragments comprising them. No. 1-L is composed of acid volcanic glass fragments, including pieces of glass that are pumiceous, obsidian fragments with characteristic flow structure, pieces of perlitic glass, and pieces of vitrophyre and other rock fragments, as well as many broken and much modified fragments of alkali feldspar and acid plagioclase. Crystals of magnetite and apatite are associated with some of the lithic fragments and veinlets of perfectly fresh pyrite cut all the structures in the rock, transecting many of the magnetite grains. All of the lithic and mineral fragments are closely packed in a small amount of groundmass that consisted initially of acid glassy ash, now thoroughly devitrified. In addition to the devitrification product of the finer glass particles, chlorite, hematite, dusty and granular magnetite, quartz and leucoxene, have developed as alteration effects.



FIG. 9 – *Río Coca 1-L* – Devitrified acid volcanic tuff. Photomicrograph, ordinary light, showing clastic character. Note perlitic glass fragments, and other glassy lava fragments. The black streak cutting the rock is an interrupted veinlet of pyrite. $\times 34$.

The rock has been fractured likewise, and quartz, albite and pyrite were introduced. It is a devitrified, acid, volcanic tuff. Figure 9 illustrates the fragmental habit and the nature of the fragments.

- **Sample No. L-a** was initially a fine acid ash, carrying small, broken and angular pieces of quartz and both alkali and acid plagioclase feldspar. The chief modification product is a quartzose and feldspathic devitrification aggregate, although a little leucoxene, chlorite and sericite have likewise been produced. The texture has been coarsened by devitrification and many wholly modified remnants (“ghosts”) of shards of volcanic glass are distributed through the rock. It is a devitrified volcanic ash.

- **Specimen No. 18**, from the next stratigraphically higher horizon and from a point 60.5 miles from the mouth of the Río Coca, elevation 2050 feet, is a strongly modified, indurated and slightly tuffaceous rock with trachytoid groundmass, whose phenocrysts consist of both acid plagioclase and alkali feldspar, some of which show partial saussuritization; whereas in others, zoisite, epidote, sericite and albite occur in separate individual grains and patches. In this specimen, also, the general groundmass is extremely patchy and different in aspect from place to place, yet aside from the obvious lithic fragments, which are much altered but readily recognizable as distinctly different lithic units, the various unlike areas in the groundmass merge into one another by imperceptible gradations. Thus, despite the patchy behavior, the rock appears to be of definitely pyrogenic rather than pyroclastic origin. The rock carries larger crystals of magnetite and apatite than the other rocks of this series. Small crystals of pyroxene, but of phenocrystic dimensions, are completely altered to serpentine, and in rare instances to a mixture of quartz, epidote, zoisite and serpentine. The rock is intermediate between the trachytes and andesites. It is a porphyritic latite or trachy-andesite, modified and indurated.

- **Sample No. Z**, from 60 miles above the mouth of the Coca, elevation 2008 feet, represents a horizon nearer the sediments. It is a porphyritic rock with flow structure, initially of andesite make-up, but now completely modified and strongly indurated. The original, moderately basic, plagioclase phenocrysts are composed of mixed aggregates of coarse sericite, granular calcite, quartz, albite and epidote, all forming aggregate pseudomorphs after the original feldspar. Phenocrysts of original hornblende that initially was resorbed along the margins, have been altered to a mixture of calcite, epidote in fan-like, radiate acicular groups and a little quartz, all pseudomorphs after the former hornblende. The structures of the former resorbed margins are preserved as pseudomorphs composed of an opaque-white substance; this may be leucoxene derived from the alteration of possibly titaniferous granular magnetite that was formed during the resorption of the original hornblende.

The small plagioclase laths in the groundmass are likewise faithfully reproduced as mixed aggregate pseudomorphs, similar to the much larger phenocrysts of feldspar.

Patches of carbonate, containing perhaps a little iron and magnesia, in addition to lime, and small irregular areas of secondary aggregate-quartz, are scattered through the groundmass, products of the alteration of portions of it, and interstitial to the small groundmass feldspars. The rock contains also small irregular areas filled with chlorite and mosaic quartz, which suggest that leaching and filling were operative among the secondary processes which have affected the rock so profoundly. Most, if not all, of the primary substances have been destroyed. A few minute apatite crystals and euhedral grains of possible primary magnetite are the only originals remaining.

The rock consists now of coarse sericite, albite, quartz, calcite and other carbonate, epidote, zoisite, chlorite, leucoxene and a little hematite. The striking thing is the retention of the former structures in the rock notwithstanding the complete change of its substance. It is a meta-andesite.

- ***Specimen No. 6***, from a massive outcrop at the lower falls of the Río Coca, 58 miles from the mouth, elevation 2000 feet, represents the next horizon of these igneous rocks nearer to the sediments. This rock is so variable in texture from place to place that it is suggestive of a volcanic fragmental, but while there are a few distinct lithic fragments whose composition is different from the main part of the rock, most of the mass is andesitic. The groundmass changes in quality gradually; in some places there is a distinct pilitic structure common to andesites; other places exhibit a fine granular structure, and still other portions of the rock are more coarsely pilitic with good flow structure. All of these apparently different units grade into one another so there are no distinctly outlined individual fragments with the exception of those previously mentioned. It is difficult to say whether the rock was initially a volcanic tuff of somewhat uniform andesitic make-up, whose separate fragments have been obscured through alteration, or whether it is an andesitic lava that is strongly xenolithic and whose caught-up fragments have not only been sufficiently worked over to have lost their sharp outlines, but also still more obscured by alteration. The general aspect presented by the rock is that of a lava crowded with inclusions, some of which may be cognate inclusions, whereas others are distinct xenoliths of basaltic composition. These latter contain beautiful aggregate pseudomorphs of granular (mosaic) quartz after both pyroxene and olivine mixed in some cases with a little serpentine, and very irregular patches representing former cavities made by leaching, now filled with matted, acicular, greenish serpentinous aggregates that are almost isotropic, surrounded with much more strongly anisotropic matter that is composed of a mass of minute, interlocking scales, very much like fine sericite or talc, the whole margined with a very narrow strip containing fibers set perpendicular to the walls, resembling chrysotile in habit. Some of the patches carry feldspar phenocrysts which have been in part altered to quartz, sericite, zoisite-epidote and albite, and occasional phenocrysts of feldspar contain channels, formed perhaps by leaching, filled with the same fine serpentinous aggregate just described.

More or less leucoxene, granular titanite, chlorite, magnetite and limonitic matter are distributed through the rock in finely granular aggregates. The sample represents either a strongly indurated and modified, but remarkably uniform, andesitic tuff, or a highly tuffaceous andesite. It is probably the latter.

Comment on Analysis: A comparison of the chemical analysis of this rock with the average analysis of twelve andesites shows that both silica and alumina are appreciably higher in Río Coca No. 6, and both lime and magnesia are considerably lower. There is less than half the amount of lime in the Río Coca sample than is shown in the average andesite, and approximately but three-fourths as much magnesia. While the potash and soda, lower and higher respectively in the Río Coca sample, differ from the average andesite, they are nevertheless within the range of variation shown by the andesites themselves. The total iron content is higher in the average andesite, and manganous oxide lower; the greater part of the iron in the Río Coca sample is present in the higher state of oxidation, and the manganous oxide is rather high. Considering the altered condition of the rock, it corresponds fairly well with the composition of andesites in general.

The next higher horizon in these igneous rocks is represented by samples Nos. 1, 1-a, 2, 3, 4 and 5, from a point of 58 miles from the mouth, elevation 1936 feet. The outcrop is massive, possibly slightly stratified, jointed, and containing inclusions. They are all intensely altered, a condition common to every one of the Río Coca samples. Nos. 1 and 1-a represent material a few feet higher stratigraphically than Nos. 2 and 3.

- *Sample No. 1* is very slightly porphyritic, with a trachytoid fabric, the feldspars consisting of plagioclase laths distributed among crystals of alkali feldspars that are somewhat larger than the plagioclase laths, but not of phenocrystic dimensions. All the feldspar is altered. Sparingly distributed granules of former pyroxene have been converted into a mixed modification-aggregate consisting of serpentine and chlorite. The rock is essentially an altered trachy-andesite, or latite.

- *Specimen No. 1-a* is much more obscure. It carries feldspar crystals that seem to be phenocrysts, but the rock is either strongly tuffaceous or else a real fragmental. The phenocrysts of feldspar are chiefly of the alkali type, although acid plagioclase is present among them. All of them are more or less sericitized, and occasionally granules of epidote appear as one of their modification products. Many of them exhibit a streaked and patchy appearance common to feldspar that has been partially albitized, and these feldspars are judged to have been modified by sericitization, albitization and, to a very slight degree, by epidotization.



FIG. 10 – *Río Coca No. 1a* – Tuffaceous and porphyritic latite. Photomicrograph, ordinary light, showing the very obscurely fragmental habit, porphyritic structure and groups of partially albitized feldspar phenocrysts. The rock is highly variable in texture and groundmass habit from place to place and very strongly tuffaceous, but the fragments or xenoliths are so much modified that they merge into one another, and are only indistinctly outlined. $\times 24$.

The groundmass of the rock is extremely variable, changing in texture, structure and in composition from place to place. Some areas exhibit typical hyalopilitic structures characteristic of andesites; other places are finely felsitic, almost glassy, with minute feldspars and fragments of crystals distributed in them; and still other areas, felsitic or finely granular, carry feldspar phenocrysts themselves, suggesting fragments of a porphyritic volcanic of some sort. Yet, with a few exceptions, these areas are not sharply outlined; they have all been obscured through alteration and they merge imperceptibly into one another.

Coarsely crystalline epidote, mixed with zoisite and quartz, forms aggregate pseudomorphs after pyroxene, both single and grouped; the grouped pseudomorphs carry numerous included euhedral grains of magnetite.

There are indistinctly outlined areas in the rock composed of epidote and zoisite, suggestive of possible basic lithic fragments that have been completely destroyed by alteration; and non-pleochroic, light-green serpentine aggregates pseudomorphous after forms suggestive of hornblende.

The rock is judged to be a very much altered, strongly indurated, obscurely fragmental or strongly tuffaceous volcanic with the composition of trachy-andesite or latite; essentially it is an extensively altered, tuffaceous and porphyritic latite. Figure 10 illustrates this rock.

- ***Specimen No. 2*** is lower stratigraphically than No. 1, and pyroclastic in origin. It is composed of fragments of obsidian with flow structures, pieces of perlitic glass, and fragments of vitrophyre and keratophyre, all very much altered. Many broken crystals of both alkali feldspar and plagioclase are contained in the rock, some partially, others almost completely, altered to mixed aggregates consisting of sericite, patches of albite and granular epidote. Considerable epidote and a little calcite occur all through the rock, and much mosaic quartz has developed through the silicification of some of the lithic fragments whose former perlitic, pumiceous and flow structures are retained only as “ghost” or inherited structures. Minute fractures in the rock are filled with quartz, calcite and epidote.

It is an indurated, intensely modified, moderately acid volcanic tuff, with the composition of a trachyte or latite.

- ***Specimen No. 3***, taken from the neighborhood of No. 2, is a fine, thoroughly devitrified, spherulitic felsite; probably a devitrified spherulitic glassy lava originally, fractured and healed with quartz, which not only fills the fractures but which also encroaches on the substance of the rock as well. The primary spherulitic structure exists now as a relic or “ghost” structure, since the rock has been very extensively modified.

- ***Specimens Nos. 4 and 5***, taken from the same vicinity as Nos. 1, 1-a, 2, and 3, are different in initial make-up, although they have suffered in the same way as the others from intense hydrothermal attack. ***Sample No. 4*** is of pyroclastic origin, carrying many fragments of various sorts of igneous rock, ranging from acid perlitic lavas to pieces of andesitic rock, and fragments of broken feldspars. All the fragments are much altered; chlorite, serpentine, epidote, quartz, magnetite and leucosene are the dominant secondary substances, and the rock has also been silicified to some degree through the introduction of quartz.

The original clastic character of the rock has been considerably obscured by these changes; the same set of products has developed in the initially fine groundmass in which the lithic fragments are distributed, and rather extensive devitrification has likewise been brought about. It is essentially a much-modified volcanic tuff of about trachy-andesite make-up.

- **Sample No. 5**, from the same vicinity as No. 4, is very different from No. 4, and from all the preceding samples of the Río Coca series. It is very strongly porphyritic, the larger phenocrysts consisting of augite, much fractured within the crystals, which contain areas that are somewhat granular. The augite crystals have a habit of close grouping, so that aggregate or compound phenocryst composed of closely knit but differently oriented units result.

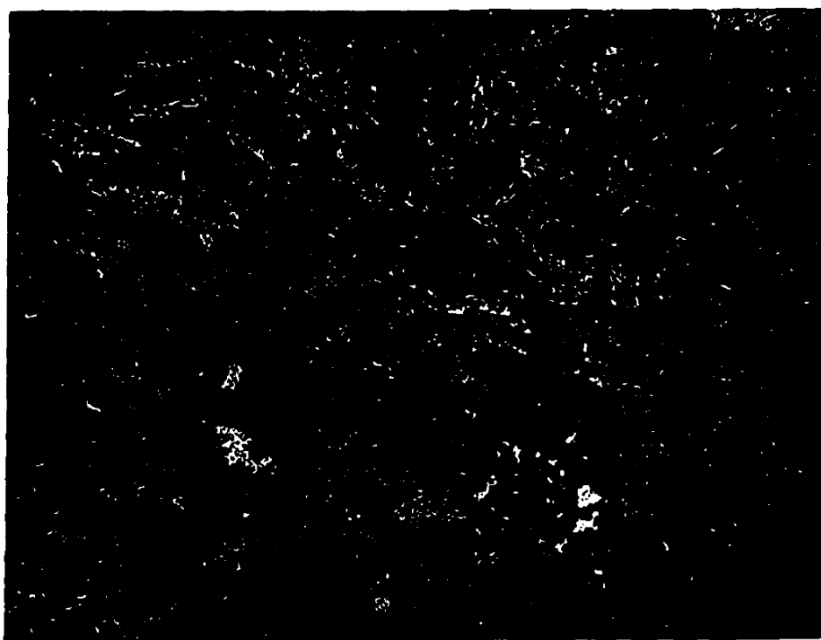


FIG. 11 – *Río Coca No. 5* – Modified Basalt. Photomicrograph, ordinary light, showing strongly modified feldspars, and aggregate pseudomorphs of epidote, quartz, calcite and penninite after augite (in the lower part of the picture). The black groundmass in which all the crystals are distributed is basic glass, now partially altered to an opaque white product judged to be anauxite. $\times 24$.

The birefringence of the augite does not exceed 0.030, the pleochroism is imperceptible and Z_{ac} is approximately 45° . Some of the augite crystals are wholly altered, others only slightly altered; the alteration products are epidote, quartz, penninite and calcite. Penninite, occasionally mixed with a little calcite and quartz, likewise occurs pseudomorphous after olivine; the crystals (pseudomorphs) are smaller than the augite and frequently sharply idiomorphic.

The plagioclase, both as phenocrysts and as small laths distributed in the groundmass, is labradorite. It has been more or less modified, however, so that it consists in part of alteration aggregates composed of fine mixed sericite, epidote, carbonate, and zoisite.

Interstitial basic glass forms part of the groundmass of the rock, but it appears opaque white in thin section, consisting now of one of the kaolin minerals, probably anauxite. The general character of the rock is shown in Figure 11; the black interstitial groundmass is really opaque white by reflected light. The rock is a modified basalt.

- **Specimen No. 17.** Immediately underlying the sediments occurs igneous rock presented by Sample No. 17, collected at a point 56.5 miles from the mouth of the Río Coca, at an elevation of 1864 feet. The outcrop is massive and vein-streaked. This very fine textured black rock is slightly porphyritic with a beautiful fluxion structure emphasized by microlites of labradorite, which are not greatly modified, set in a mesostasis of glass. The phenocrysts consist of colorless pyroxene, resembling in optical and structural characters that described as occurring in Sample No. 5; and mixed pseudomorphs of limonite, carbonate and chalcedony after olivine.

As in Specimen No. 5, several units of pyroxene form closely knit groups, each individual of the group having a different orientation, making compound phenocrysts. In most cases several, sometimes each one, of these units have been partly altered to clear granular carbonate, probably calcite, different in appearance and behavior from the carbonate that is contained within the destroyed olivine crystals and which is distributed in patches all through the groundmass of the rock in the form of a very finely granular aggregate with a turbid aspect, quite unlike the large clear calcite grains in the pyroxene. A number of small fractures, filled with later mosaic-quartz and calcite, transect the rock, cutting through groundmass, carbonated patches in the groundmass, and phenocrysts, indifferently. The specimen is on the border between andesites and basalts; it is strongly feldspathic and possesses the characteristic hyalopilitic fabric of andesite, but the ferro-magnesian components are pyroxene and olivine and the feldspar is labradorite. It is essentially a basaltic andesite. Figure 12 illustrates this rock.

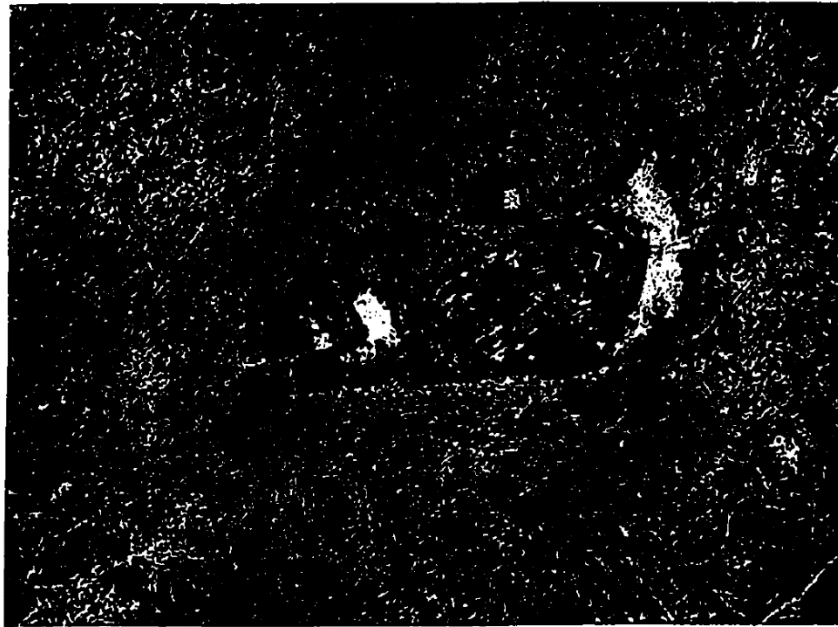


FIG. 12 – *Río Coca No. 17* – Basaltic andesite. Photomicrograph, ordinary light, showing tiny labradorite microlites in fluxion structure, and one of the completely altered olivine phenocrysts. These consist of mixed aggregates of limonite, carbonate and chalcedony, pseudomorphs after the original olivine. $\times 24$.

Río Misahuallí Series

About sixty-two miles in an air-line southwest of the Río Coca volcanics, and also underlying almost-horizontal sediments, some of them of proved Albian age, there is another series of altered volcanics of unknown thickness; their base is not exposed. These outcrop in the bottom of another deep canyon, that of Río Misahuallí, at an elevation of about 1500 feet.

About 100 feet of these rocks are exposed at the river surface. At this locality marine limestones of Albian age are separated from the underlying volcanics by about 400 feet of sandstone, which is absent on the Río Coca at the same horizon. We do not know whether any pre-Albian sediments are represented here or not. As in the Río Coca series the underlying volcanics represent flows and tuffs, now greatly altered, all of which are certainly much older than the Albian.

- **Sample No. 73.** The rock immediately underlying the sediments and corresponding in horizon to the basaltic andesite (Specimen No. 17) of the Río Coca, is exposed in cliffs composed of massive grayish-pink to yellowish streaked rock. The sample, which was collected on October 11, 1921, was secured from a place about three miles below the mouth of the Río Hollín.

The specimen is somewhat obscurely fragmental and considerably altered. The most conspicuous fragments are those in which alteration has produced both hematite and limonite; these stand out sharply from the more obscure fragments in which alteration has taken other forms.

The fragments consist of andesite, whose interstitial groundmass is thoroughly altered and heavily charged with hematite, and whose feldspar microlites are also modified; altered pieces of vitrophyre, some charged with hematite, others stained by limonitic products, pieces of much altered basaltic vitrophyre, pieces of keratophyre not so badly modified, pieces of dacite carrying phenocrysts of plagioclase and small corroded phenocrysts of quartz; broken crystals of orthoclase, slightly sericitized, large crystals of plagioclase of oligoclase-andesine composition, usually more or less fractured, slightly sericitized, stained with limonite and charged with hematite; thoroughly altered biotite crystals and broken hornblende, almost completely converted to mixed hematite-limonite; and much secondary quartz in fine grains and patches of fine mosaic-like aggregates. Crystals of modified titanite and limonite pseudomorphs after pyrite are sparingly distributed through the general groundmass. The rock as a whole is stained with limonite and contains streaks and patches of hematite, kaolinitic matter and leucoxene.

It is difficult to classify a mixed fragmental of this character; the average composition of the rock is judged to be intermediate between the rhyolites and dacites, and for all practical purposes it may be regarded as a very much modified dellenitic tuff.

Figure 13 shows one of the more conspicuous fragments, that stands out prominently from the more obscure fragments surrounding it.



FIG. 13 – *Río Misahuallí No. 73* – Dellenitic tuff. Photomicrograph, ordinary light, showing one of the more prominently outlined andesite fragments, and other fragments, very much obscure, owing to the extensive alteration. The small white patch on the right of the large fragment is quartz. $\times 24$.

- ***Specimens A and 69*** were collected immediately underneath the dellenitic tuff (Sample 73) just described, two miles farther up the Misahuallí River, and about one mile below the mouth of the Hollín River.

- ***Sample A*** has a finely felsitic groundmass in which microphenocrysts of feldspar are distributed. Orthoclase, micropertite, and plagioclase that has the composition of oligoclase-albite, as nearly as could be determined, are all represented among the tiny feldspar crystals. They have all been more or less modified. Ferromagnesian are almost lacking in the rock; the few crystals consist of bleached biotite carrying little granules of zoisite and patches of leucoxene.

Very small xenoliths are sparingly scattered through the groundmass, which is somewhat variable in habit from place to place, but this feature is rather obscure owing to alteration and to the development of fine secondary quartz.

The rock is undoubtedly tuffaceous, if not actually fragmental; it has the general composition of a trachyte, but it lacks the structure characteristic of true trachytes. It is essentially an exceedingly fine textured, altered and tuffaceous trachytic felsophyre, or possibly a modified and strongly indurated trachytic ash.

The fine texture of the rock, its altered condition, and the abundance of fine secondary quartz, are shown in Figure 14.

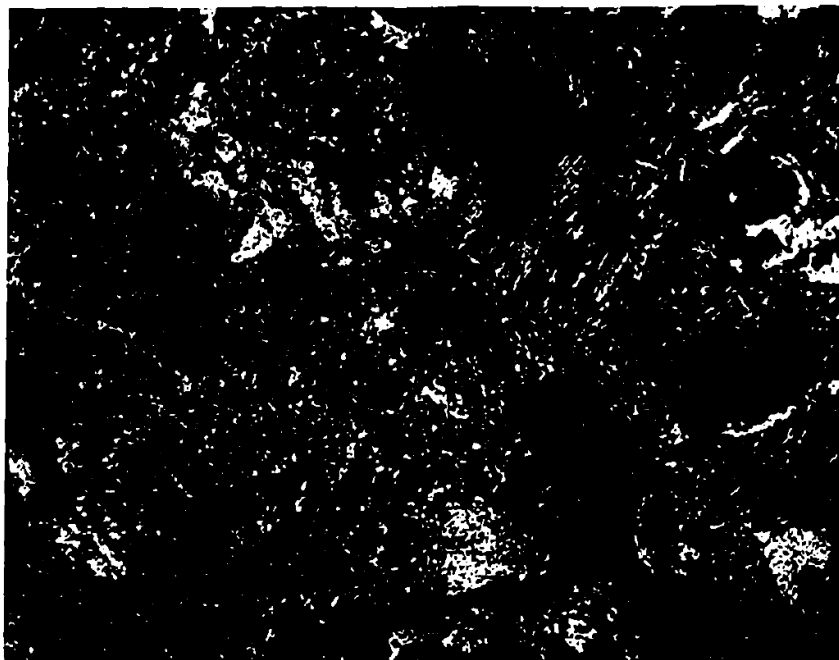


FIG 14 – *Río Misahuallí No. A* – Indurated, altered tuffaceous trachytic felsophyre. Photomicrograph, nicols crossed, showing the strongly silicified condition of the rock. Most of the small white specks are quartz of secondary origin. The larger white patches are feldspar, the black ragged patches are holes in the section. $\times 60$.

• **Sample 69** is also finely felsitic, with a few small completely kaolinized microphenocrysts of feldspar and an occasional bleached and completely modified biotite crystal distributed through the groundmass, which is composed almost wholly of a micro-granular, interlocking aggregate of alkalic feldspar, minutely micrographic in places, very slightly sericitized, containing minute, scattered patches of carbonate and a little secondary quartz.

The rock is veined with calcite with which is associated a little pyrite and what appears to have been siderite that has been entirely altered to mixed red-black hematite and to carbonate.

This sample is essentially the same as Sample A in general composition, but the groundmass is much more uniform both in structure and texture, and there is no suggestion of fragmental habit at all. It is essentially a trachytic felsophyre.

Some of the features mentioned are illustrated in Figure 15, which shows the microgranular character of the groundmass and one of the kaolinized and slightly sericitized little feldspar crystals.

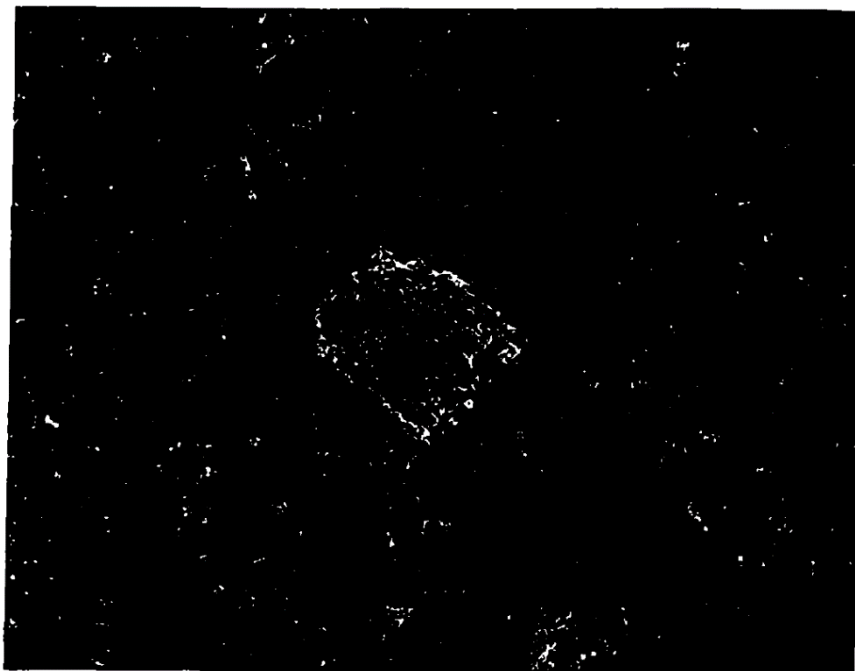


FIG. 15 – *Río Misahuallí No. 69* – Altered trachytic felsophyre. Photomicrograph, nicols crossed, showing altered feldspar phenocryst and microgranular groundmass of feldspar. $\times 60$.

- *Specimens 71, 71-a, 71-b and 72* represent the lowest formations, stratigraphically, encountered on the Misahuallí River. The samples were taken from an outcrop along the river about two miles below the mouth of the Hollín River. The rocks here dip 10° west, upstream. In the field the weathered exposure strongly resembles a conglomerate, containing rounded “pebbles” up to two or three inches in diameter. These “pebbles”, however, proved to be amygdaloidal fillings in an originally extremely porous basalt.

- *Samples 71, 71-a, 71-b* are different specimens taken from the same formation. the rock is composed of small plagioclase laths and somewhat larger crystals of the same substance, all very considerably modified. The alteration is saussuritic in character, consisting of patches of sericite, chlorite and excessively finely microgranular zoisite distributed in new and more acid feldspar than that which originally composed the laths.

Much larger crystals of phenocrystic dimensions have been altered to mosaic-like aggregates of quartz, mixed with faintly green mica, the whole forming beautifully pseudomorphic aggregates after what is judged to have been originally pyroxene. Small olivine crystals, now consisting of an alteration complex of various forms of serpentine, mixed with carbonate, are sparsely disseminate through the groundmass, which consists of brown basic glass, in which all of the altered crystals mentioned above are distributed. Some of the vesicles are filled with quartz in the form of both mosaic-like aggregates and feathery chalcedony, mixed, in some cases, with carbonate and zeolites, and others are filled with carbonate. Quartz and chalcedony form the major part of the fillings, so that the round and ovoid amygdules, being much more resistant to weathering than the rock itself, have weathered in relief, thus giving the rock the aspect of a conglomerate in the field.



FIG. 16 – *Río Misahuallí No. 71* – Altered basaltic amygdaloid. Photomicrograph, nicols crossed, showing ovoid or lenticular amygdule of aggregate quartz, quartz pseudomorphous after pyroxene, completely altered feldspar and dark altered glassy groundmass. $\times 21$.

Little cubes of pyrite, some still unaltered, others partially and wholly converted to limonite, are associated with the mosaic-like quartz aggregates pseudomorphous after pyroxene previously mentioned, and veinlets of mixed quartz-chalcedony traverse the rock, containing as part of the mixed vein-filling a black metallic mineral of some sort not determinable in thin section. Extremely irregular cavities, evidently produced by leaching are also filled with the quartz-chalcedony aggregate similar to that which occupies the primary vesicles. The brown, basic, glassy groundmass is itself altered to a translucent product, white by reflected light, and presumably of kaolinitic nature, although the “glassy” groundmass is still brownish in color by transmitted light.

The rock is an altered, glassy basaltic amygdaloid, rather uncommonly vesicular originally, containing abundant amygdules of considerable size.

- **Sample 72 (a-b and c)** was secured in the same locality as Sample 71, and represents the same formation. It is similar to No. 71 in composition, structure and alteration effects, but carbonate as a secondary product is much more prominent than in No. 71. Irregular leaching cavities, now filled, are more numerous in this sample, but the rock is not much different otherwise.

The plagioclase is greatly altered and original pyroxene and olivine are entirely destroyed; they are represented now by complex aggregate pseudomorphs consisting of quartz, carbonate, serpentine and limonitic products, and the initially glassy groundmass is more or less kaolinized and stained with limonite. Figures 16 and 17 illustrate different specimens of this rock.

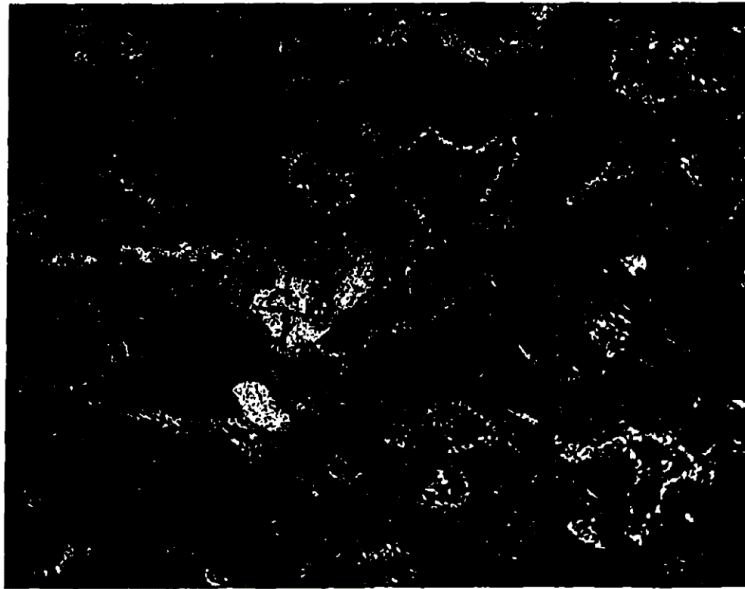


FIG. 17 – *Río Misahuallí No. 72-b* – Altered amygdaloidal basalt. Photomicrograph, nicols crossed, showing cavities formed by leaching, filled in part with calcite, in part with fine serpentinous matter; and completely altered feldspar laths distributed in an altered, dark, glassy base. $\times 21$.

Río Jandache Series

The third place where the base of the sediments and the underlying igneous rocks were encountered is about 20 miles north of the occurrence on the Misahuallí River and about 50 miles in air-line southwest of the Coca River locality.

Here the sediments terminate against the Guacamayos mountains at an elevation of 4000 feet above sea level. They form cliffs in the valley of the Jandache River where the trail from Quito to the Napo River crosses the valley.

The presence of these sediments, and the underlying igneous rocks similar in character to the volcanic rocks and associated overlying sediments found at the Coca River and the Misahuallí River, afford additional evidence of the existence of a widely distributed sedimentary series lying unconformably on a series of much older, altered igneous rocks of surface volcanic types.

- *Specimen B*, collected from the cliffs and beneath the sediments of the Jandache River, is a spherulitic, porphyritic and devitrified lava, with a composition intermediate between a rhyolite and dacite.

The rock was initially a porphyritic glass containing spherulites, small phenocrysts of oligoclase and orthoclase, little biotite crystals now thoroughly bleached and spotted with magnetite, limonite, leucoxene and hematite, and multitudes of crystallites distributed through the originally glassy groundmass in swirling flow lines. The primarily glassy groundmass consists of an unusually coarse and intricately interlocked devitrification aggregate composed of quartz and feldspar, which retains traces of replaced spherulites and through which the lines and streams of crystallites pass uninterrupted.

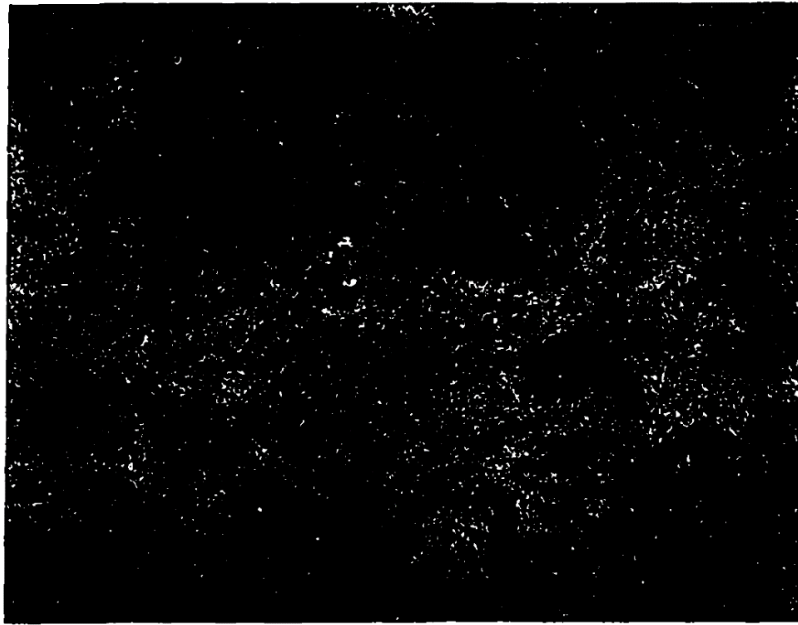


FIG. 18 – *Río Jandache No. B* – Devitrified altered dellenitic vitrophyre. Photomicrograph, ordinary light, showing fine and originally glassy microlite groundmass, with flowage and traces of spherulites, and an altered orthoclase phenocryst. $\times 25$.

The feldspar phenocrysts are slightly kaolinized and flecked with tiny scales of sericite, and a few small hornblende crystals in the groundmass have been so thoroughly destroyed by the alteration attack that only their outlines remain. They consist now of an aggregate of quartz mixed with a little fine flaky mica and limonite. The rock is a coarsely devitrified dellenitic vitrophyre. Some of the features mentioned are shown in Figure 18 and 19.

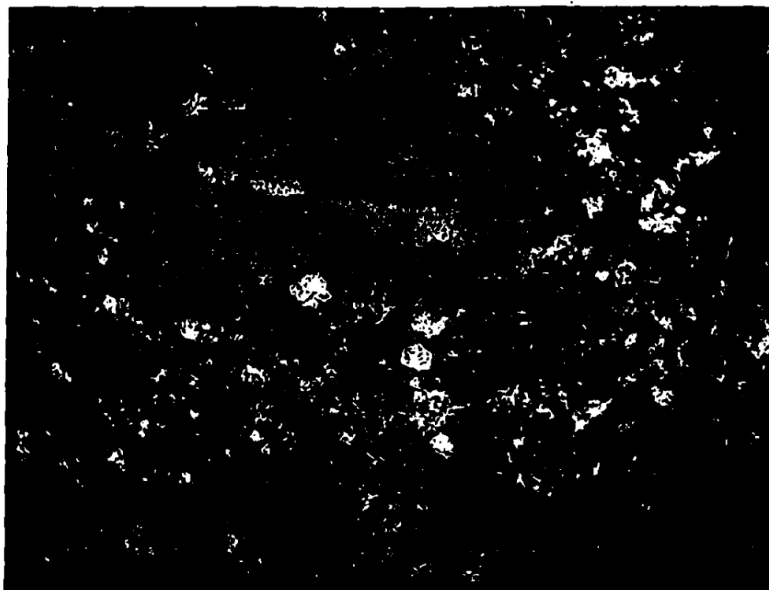


FIG. 19 – *Río Jandache No. B* – Photomicrograph, same field seen in Fig. 18, nicols crossed, showing complete devitrification of the former glassy groundmass, and altered phenocryst of orthoclase. $\times 21$.

b. Igneous rocks of probable pre-Albian age*Río Pastaza Series*

In the gorge of the Pastaza River, between the mouth of Río Topo, which lies at an elevation of 4000 feet, and the hamlet of Mera, 3800 feet above sea level, 47 miles and 56 miles, respectively by trail from the city of Ambato, there is a narrow belt of igneous rocks nine miles in width, lying between exposures of sediments, on the one end at the mouth of the Topo River and on the other just east of the village of Mera.

The sediments at Topo River are limestones, shales and sandstones, containing fossils. A good collection of these was made but it was unfortunately lost in transit. We believe these rocks are Cretaceous. They dip westward at an angle of 55° , striking nearly north-south. The sediments just east of the village of Mera are Cretaceous.

On the east bank of the Topo River there are blocks of reddish granite, and exposures of this granite occur in Zuñac creek, which lies a mile to the east. The granite may be traced as far as a hut called “Tamba de Cashaurcu”, 7.75 miles by trail from the Topo River, and lying at an elevation of 4674 feet above sea level. In the midst of the granite, which apparently forms the surface almost as far as the village of Mera, and between a high ridge to the eastward known as Abitagua and a point about one and a half hours’ walk from the hut called Cashaurcu, there is an outcrop of igneous rock of surface volcanic type, resembling the previously described pre-Albian rocks of the Coca, Misahuallí and Jandache Rivers.

Since this exposure is not directly associated with any of the sediments the age of these volcanics is unknown.

- *Specimens 7a and 7c* were secured from the exposure mentioned, on the north side of the Pastaza Valley about three miles west of Mera.

- *Sample 7a* is coarsely felsitic in texture. It is composed of dominant alkali feldspar and quartz in beautiful micrographic intergrowths, occasional slightly larger individual allotriomorphic quartz grains and small patches of mosaic-like aggregates of quartz, the whole forming over 95 per cent of the rock. Tiny shred of chloritized biotite and a few chloritized crystals of the same mineral, of phenocrystic dimensions, are scattered through the groundmass, together with a few small aggregate patches of zoisite-epidote. The most striking thing about the rock is its micrographic structure. Minute euhedral crystals of plagioclase feldspar, of acid oligoclase composition, are set in poikilitic fashion in individual micrographic areas, different sections of which extinguish differently so that the micrographic units simulate crude and extremely coarse spherulites.

In composition the rock is a rhyolite, although it lacks flow structure.

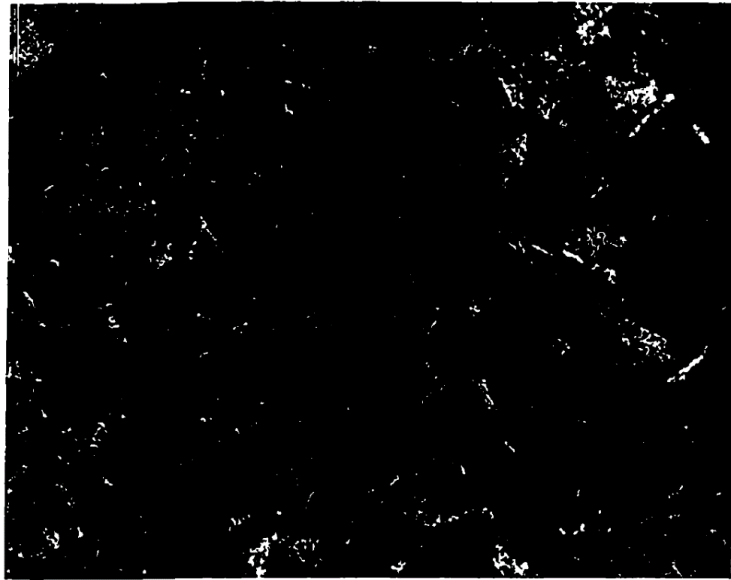


FIG. 20 – *Pastaza Valley No 7a* – Rhyolite. Photomicrograph, nicols crossed, showing finely micrographic quartz-feldspar groundmass containing small euhedral laths of oligoclase in the micrographic areas, and anhedral grains of quartz. $\times 60$.

- **Sample 7c** is finer textured than No. 7a, and lacks the very striking micrographic structure displayed by that specimen. The groundmass consists of a closely interlocking fine aggregate of alkali feldspar, carrying numerous fine scales of sericite. Both orthoclase and acid oligoclase occur as phenocrysts, as well as corroded quartz crystals. A few bleached biotite crystals spotted with little patches of leucoxene represent the only other component in the rock. Like No. 7a, this specimen is a simple rhyolite, lacking flow structure. Figures 20 and 21 illustrates these two rocks.

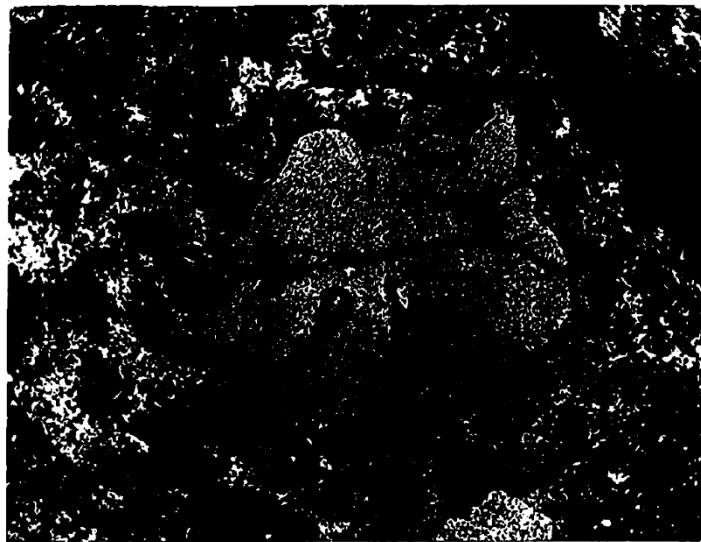


FIG. 21 – *Pastaza Valley No. 7c* – Rhyolite. Photomicrograph, nicols crossed, showing partially resorbed quartz phenocryst and groundmass of fine, interlocking microcrystalline aggregate of feldspar, more or less sericitized. $\times 60$.

“Cordillera” Guacamayos Series

- **Specimen A, B and C.** About twelve miles, in an air-line, south of the village of Baeza on the trail to the Napo River there is a prominent but narrow ridge whose crest rises to an elevation of 7870 feet above the sea. Six miles south of this summit, at the base of the ridge, the trail crosses the Río Jandache where, as previously mentioned, the pre-Albian sediments terminate in the south slope of the valley and are underlain by altered volcanics.

The rocks of the “Cordillera” Guacamayos, probably of the same age as the pre-Albian volcanics, are badly weathered, rusty, brown and white mottled, and contain chalky white spots.

- Although **Specimen A** is very much altered there are distinct traces left of its former texture and structure. It is coarsely porphyritic, with large phenocrysts of altered plagioclase feldspar and Carlsbad twins of alkali feldspar distributed in a moderately coarsely crystalline groundmass composed of smaller laths of altered plagioclase, and plates of bleached biotite. Larger crystals of biotite, of phenocrystic dimensions, are likewise distributed through the rock. Most of the feldspar is thoroughly altered; all of it has been sericitized and a great deal of it has been albitized. The rock has been flooded with quartz and albite to such a degree that the original groundmass-feldspar laths, now almost wholly modified in composition, are distributed in a much coarser textured mosaic of albite and quartz, which is filled with “dust” outlining the forms of the earlier replaced feldspar, and with bubble and liquid inclusions as well.

Here and there albite twinning may be observed in some of the feldspar phenocrysts, but the clear feldspars of the phenocrysts are crowded with bubble and liquid inclusions; this feldspar is judged to be later replacement albite. All the biotite is bleached, wholly or in large part, with the development of brilliantly polarizing colorless mica, a faintly green pleochroic mica that is also brilliantly polarizing, a little granular titanite, granular magnetite, and a little leucoxene. Fine flaky chlorite is also a product of the same process.

There is no evidence of crushing or shearing, but the rock is so thoroughly modified by processes that were under igneous control that provided the extent of this sort of modification may be considered a criterion, this rock belongs to the older group; that is, it is probably older than the late Andean lavas (pre-Quaternary). Weathering has produced limonitic and kaolinitic products, subsequent to the modification of the rock by the metasomatic replacement by quartz and albite. A little of the quartz may be primary, more especially in scattered areas where it has an interstitial distribution. It is almost impossible to differentiate, however, between original quartz and that which is associated with the albite as replacement quartz. So far as can be judged the rock is a much modified and extensively weathered monzonite porphyry, or a closely related type.

- **Sample B.** This specimen carries, phenocrysts of embayed quartz, in many instances surrounded by and in all cases connected with and encroached upon by very coarsely spherulitic feldspar, which is associated not only with the quartz phenocrysts but which also occurs in close connection with the feldspar phenocrysts as well. Very much smaller spherulites with the same composition are distributed all through the granular quartz-feldspar groundmass.

The feldspars, both as phenocrysts and in the groundmass, are almost completely altered; in part to fine flaky sericite; in part to an opaque-white finely granular product that causes the feldspar to look very dark and turbid by transmitted light, probably a form of kaolinite; and in part to a low index, transparent but milky isotropic substance that may perhaps be halloysite (?). The feldspars still show traces of both albite and Carlsbad twinning; they are judged to have been initially both orthoclase and soda plagioclase.

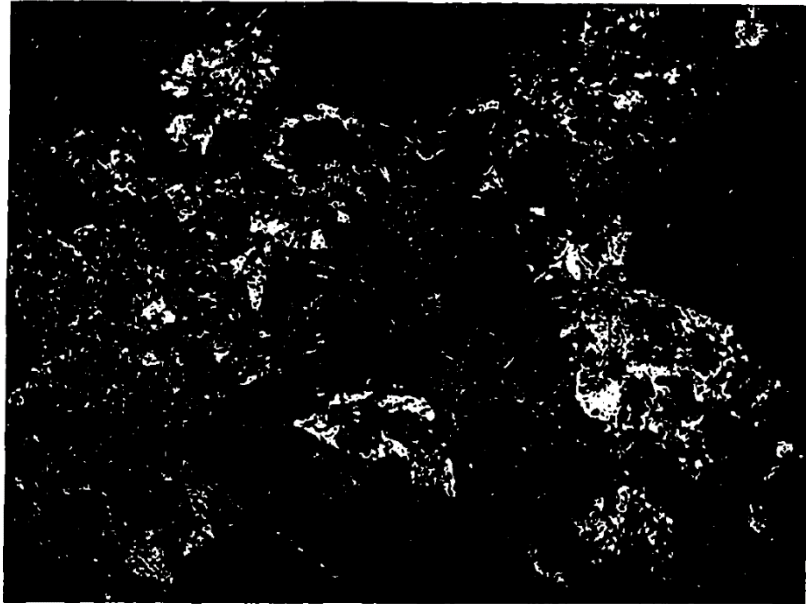


FIG. 22 – *Cordillera Guacamayos No. B* – Spherulitic granophyre. Photomicrograph, nicols crossed, showing granular groundmass of quartz-feldspar, altered feldspar phenocrysts and a spherulitic area with center of quartz. The dark crystals at top and right of picture are altered, very turbid and sericitized phenocrysts of feldspar. The rock is strongly porphyritic. $\times 20$.

The biotite has been wholly destroyed and converted into aggregate granular pseudomorphs of quartz, epidote, chlorite, magnetite and leucoxene. Superficial weathering has been productive of limonite, which has formed at the expense of some of the biotite, and which is likewise distributed in minute cracks in the rock. The halloysite (?) and the other opaque-white alteration product of the feldspars are likewise judged to be superficial weathering products. The rock is a spherulitic granophyre.

Figure 22, a photomicrograph taken with nicols crossed, illustrates the coarsely spherulitic character of the rocks, its porphyritic habit, and the moderately granular condition of parts of the groundmass that are not spherulitic.

- **Sample C** has been much more affected by weathering than either A or B. It is a granitoid rock whose feldspar, now almost completely destroyed, was a basic or moderately basic plagioclase. The original ferromagnesian has been entirely converted into a brilliantly polarizing, brownish yellow, slightly pleochroic fibrous and scaly aggregate judged to be goethite, which is distributed along the cleavages of the feldspar and in the body of the feldspar itself in fan-like groups of fibers, as well as interstitially. Much epidote and secondary quartz have developed through the alteration of the feldspars, so that the rock now consists largely of secondary aggregates and products of weathering. From the remnants of originals left and the nature of the alteration substances, the rock is judged to be a gabbro, or an allied type.

All of these samples are probably related to an earlier igneous stage than that which gave birth to the later lavas. There is no evidence, however, of any of the severe deformation that has affected the schists series of the Papallacta group.

Río Papallacta Volcanics (pre-Albian?)

In the midst of the schists of the Río Papallacta, 6.7 miles east of Papallacta, at an elevation of 8571 feet, there is an outcrop of apparently the same formation as that underlying the Albian sediments.

- *Specimen 2b*, representative of this outcrop, is a very fine textured, pinkish, and much indurated rock.

Although all the original minerals have been completely destroyed both texture and structure are beautifully preserved. Some of the lath-like feldspar and some of the originally fine interstitial groundmass have been converted into a very fine microcrystalline aggregate whose index of refraction is higher than that of the associated quartz; it is judged to be microcrystalline kaolinite. The femic components of the rock have been altered to limonite and turbid carbonate, appearing in ragged patches but also pseudomorphous after small prisms of some sort, probably either augite or hornblende. The complete destruction of the components, but at the same time the preservation of their original form and distribution, is a very striking feature.

Much quartz of secondary origin is a prominent component of the rock, and this has replaced both groundmass and feldspar. Judging from the relations between the quartz and kaolinite, the quartz is earlier; the kaolinite actually encroaches on the quartz and in many instances, it has completely replaced the secondary quartz, so that the substance of the groundmass and former feldspar is entirely kaolinite; whereas in other areas the replacement of the quartz by kaolinite is partial, the former feldspars consisting of both products. In places where the quartz is the chief replacing medium, the lath-like feldspars are structurally suggestive of former plagioclase.



FIG. 23 – *Papallacta River Volcanic No. 2b* – Photomicrograph, ordinary light, showing relic structure. The feldspars are merely “ghosts” of original plagioclase laths. They are so completely replaced by quartz and kaolinite that all traces of them disappear between crossed nicols. The interstitial groundmass has been altered to the microcrystalline kaolinite and quartz. The black patches are limonite. $\times 24$.

The rock was probably initially an andesite or some closely related type, which was thoroughly silicified and partially kaolinized. It is certainly later than the schists, but whether it may be related to some of the late Andean lavas or not it is impossible to say.

Figure 23, a photomicrograph taken in ordinary light, illustrates the feldspar forms, now completely altered. Between crossed nicols the relic structure, seen in ordinary light and shown in the photomicrograph, vanishes, a microcrystalline aggregate of quartz and kaolinite taking its place. It will be observed that the rock exhibits no signs of deformation at all and no evidence whatever of any of the intense deep-seated metamorphism that characterizes the schist series.

Río Quijos Samples (pre-Albian?)

We questionably assign to this category two samples from the Río Quijos, Nos. 11 and 12. These rocks are of doubtful origin and uncertain relations. Specimen No. 11 was secured along the road between Quijos bridge and the cable crossing over the Quijos River, one mile from Baeza, at an elevation of 5870 feet. Specimen No. 12 came from a massive outcrop on the left bank of the Río Quijos at the cable crossing, one fifth of a mile north of No. 11 at 5852 feet elevation.

- *Specimen No. 11* is a limestone breccia whose origin is obscure. It is composed of finely granular crystalline carbonate, carrying patches or fragments of very coarsely crystalline carbonate that presents evidence of severe crushing; and shattered grains and areas of quartz, transected by veinlets of carbonate.

Veinlets of carbonate cut the whole rock mass as well, intersecting, ramifying and forming a carbonate-filled fracture system in a carbonate rock that is itself a breccia.

- *Specimen No. 12* is a serpentized rock of doubtful origin. It is composed of lamellar antigorite with heterogeneous grouping in places, as well as in rosettes, blades, fan-shaped leaves and fine aggregates. Occasional patches resemble bastite, possibly representing completely destroyed orthorhombic pyroxene. In addition, there is a little fibrous anthophyllite (gedrite) and considerable carbonate with steel-gray interference colors that may contain iron and perhaps magnesia as well as lime. Irregular grains and groups of grains of magnetite and pyrrhotite are sparingly distributed through the rock, which contains no trace of any original structures unless the possible bastite areas connote former pyroxene crystals.

It is possible that this rock may have been derived from a basic igneous rock of the nature of a peridotite, but there is no definite proof of this in the sections.

c. The Granites

We have no information regarding the age of the granites of eastern Ecuador. We found them in three regions: one on the Río Pastaza, another in the country south of the Guacamayos mountain ridge, between it and the Río Jandache, and a third on the Río Napo a few miles below Napo, where the granite has a peculiar occurrence.

Río Pastaza

- **Specimen 7b.** Between the sedimentary rocks of Cretaceous age at the mouth of the Río Topo and in the vicinity of Mera, from 4000 to 3800 feet above the sea, there is a mass of red granite which is several miles wide (the distance by trail across this is nearly ten miles). We have previously referred to the presence of rhyolite in the midst of this granite (samples Nos. 7a and 7c). The presence of this granitic mass between the two sedimentary areas is peculiar but we do not know what relations exist between the granite and the sediments.

The sample of granite from the Río Pastaza was collected between the hut called Cashaurcu and a ridge called Abitagua about three miles west of Mera on the north bank of the Río Pastaza. The rock is strikingly graphic in a very coarsely microscopic way, the grains ranging from one to two millimeters in dimensions. Quartz and alkali feldspar compose over 98% of the specimen. The feldspar consists chiefly of orthoclase, cryptoperthite and very little oligoclase-albite. It is all turbid from slight kaolinization, and the quartz is crowded with liquid and gas inclusions. A few little magnetite crystals and tiny zircons represent the minor accessory components, and an occasional microscopic fracture is filled with epidote. In addition to slight kaolinization many of the feldspars are very sparingly flecked with fine scaly sericite and minute random patches of zoisite-epidote, but on the whole, the rock, a typical graphic granite, is comparatively fresh. Figure 24 illustrates the general character of this specimen.



FIG. 24 – Río Pastaza granite – Photomicrograph, nicols crossed, showing graphic structure. Over 98% of the rock consists of quartz and feldspar in graphic intergrowth. $\times 22$.

Río Urcusikiyacu

- ***Specimen a.*** The trail from the Guacamayos Ridge south toward the Río Napo crosses an area of granite lying between the base of the ridge and the Río Jandache, where the presence of altered volcanics beneath the Albian sediments which bound the south wall of the valley of the Río Jandache has previously been referred to. The sample was collected from the trail on the right bank of the Río Urcusikiyacu, 3.33 miles north of the Río Jandache at an elevation of 4630 feet above the sea. The specimen of granite collected in this locality is a coarse textured, very inequigranular, light colored rock composed of quartz, albite, microperthite, microcline-microperthite, and a little biotite. The feldspars and the biotite show only incipient alteration, and there is a slight development of limonite in minute hair-fractures in the rock. There is some evidence that the perthitic feldspars originated through partial replacement of earlier orthoclase by end-stage albite; this is shown by the extremely ragged unoriented albite streaks in the orthoclase that cuts across the cleavages, and by the interstitial and marginal distribution of albite and quartz that have effected some marginal replacement of the earlier feldspar. The rock is a simple biotite granite.

Río Napo

- ***Specimen b.*** A very peculiar occurrence of granite was observed on the Río Napo, about five miles below the pueblo of Napo. On the left bank of the river at a place called “Remolino de Latas”, nearly horizontal limestones of Turonian age were seen. On a hill about one hundred feet above the surface of the river, we encountered several boulders some six feet in diameter, lying on the limestones. We are ignorant of both the source and the origin of the granite boulders. They have the appearance of boulders transported either by glaciers or flows of lava; they may possibly represent an inlier of granite, but this is very doubtful.

The sample is a simple biotite granite that differs from the granite on the Urcusikiyacu river only in minor internal structural details, and in the degree of alteration of the feldspars. The component grains are extremely irregular in outline, with strongly interlocking margins. The interlocking of the quartz and feldspar develops into micrographic structures in places, and there is a tendency toward the production of protoclastic structures on the margins of occasional grains. The feldspars are in large part microperthite and orthoclase, with a smaller amount of oligoclase. The orthoclase and microperthite are very turbid, owing to the formation of opaque-white kaolin mixed with a little sericite and minute grains of zoisite-epidote. Some of the biotite present has been altered in part to chlorite. Occasional random grains of magnetite and a few minute grains of zircon form the only accessories.

d. Quaternary lavas

All the metamorphic and igneous rocks described in the preceding pages refer to rocks judged to be pre-Andean in age. They were probably metamorphosed and extensively altered before the uplift of the Andes, which we now believe took place in very late Tertiary time.

The lavas which were extruded and the ash which was cast forth over the surface during the formation of the Andes, and up to the present day, is characterized by freedom from alteration. The component minerals are always perfectly fresh. Where one can examine the lava streams which are still uneroded, it is possible to recognize these lavas without petrographic study.

We have previously referred to the lavas of the volcano Sumaco which, during the opening of the orifice in the Cretaceous sediments and during the activity of the volcano, were poured forth on the surrounding Cretaceous rocks. The lavas of Sumaco have been described (1), but so far, unfortunately, no one has been able to collect any samples of the lavas of the volcano "El Reventador", which came into activity in 1926 on the Río Coca.

Apart from these two centers of volcanic activity in what has been considered a region separate from the Andes, it is probable that other Quaternary and recent lavas have been poured out on the surface in other localities not yet discovered. In 1921 we noted blocks of fresh lava in several places on the sediments; on the Río Misahuallí, again on the divide between the Río Anzu and Río Puyo at about 4000 feet elevation, and also on the Río Ila a few miles above the pueblo of Napo.

The samples herewith described may represent the lower parts of recent lava flows from the volcano Antisana.

- **Sample No. 10** was collected on the trail from Papallacta to Baeza, at a point 16.3 miles east of Papallacta and at an elevation of 6290 feet above the sea. It is a very dark gray, slightly porphyritic, vesicular rock, somewhat rusty through weathering. The groundmass is composed of tiny microlites of fresh basic plagioclase crudely oriented in a flow structure and distributed in a mesostasis of dark altered glass which is filled with multitudes of specks of iron oxide. In addition, there are granules of partially altered olivine, granules of augite and little crystals of magnetite. Scattered through the groundmass there are somewhat larger, but not phenocrystic, crystals of labradorite, olivine and augite. The rock also carries phenocrysts of clear, zoned labradorite, commonly badly corroded and filled with groundmass matter that is distributed both zonally and heterogeneously in the feldspar; and crystals of augite, some euhedral, others exhibiting corrosion, with the development of almost colorless and more brilliantly polarizing margins quite distinct from the main part of the crystals. The augite is faintly pleochroic grayish-green to faint rose-pink, optically positive, $2V_c = 38^\circ-10^\circ$, and has distinct dispersion. The rock is a basalt unaffected by dynamic movements and but very slightly affected by weathering. It is certainly much younger than the schist, and perhaps younger than the silicified and kaolinized andesite No. 2-b that occurs in the vicinity of Papallacta. This, however, is purely conjectural. It is probably lava from one of the neighboring volcanoes.

- **Specimen 2** represents an occurrence near Chalmayaca, 9000 feet south of the end of the Baeza Road. It is very dark gray, fine textured and porphyritic, with "chalky" looking phenocrysts.

The groundmass is hyalocrystalline, filled with many tiny microlites of plagioclase arranged in flowage structure, and containing irregular patches of a clear, low index substance that consists of tridymite, occurring in characteristic "spearhead" or "wedge" twins. The phenocrysts are crystal clear plagioclase and wholly altered hornblende and biotite. The plagioclase is poorly twinned but very strongly zoned; the zoning is so prominent and the change in composition so continuous that the plagioclase phenocrysts do not completely extinguish in any position.

Judging from their indices of refraction, considerably higher than balsam, and approximate extinctions (complete extinction is not found) measured from cleavages, the feldspar phenocrysts have an average composition corresponding to a basic andesine. They are veined with an isotropic substance whose index of refraction is considerably lower than 1.535, resembling analcite (?), clear and colorless in transmitted light, but somewhat opalescent by reflected light.

The phenocrysts of hornblende and biotite have been completely converted into fine mixed aggregates of magnetite and hematite. A little magnetite in euhedral grains, a few small crystals of fresh augite, and occasional turbid crystals of apatite, constitute the accessory minerals.

The rock has not been subjected to any deforming stresses at all; it is a simple andesite with a simple history, much younger than the schists, and possibly related in time and origin to the basalt No. 10.

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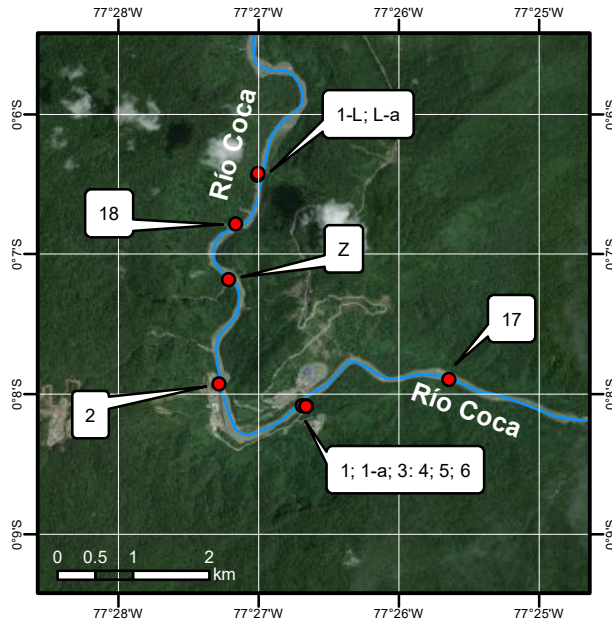
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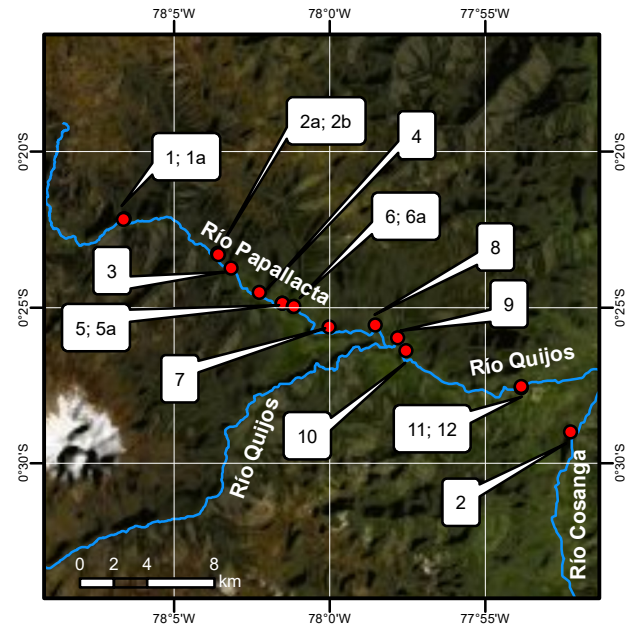
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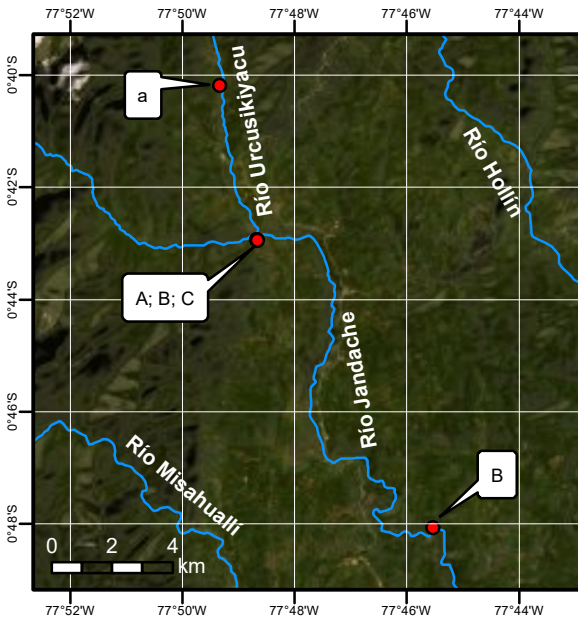
Samples' possible location



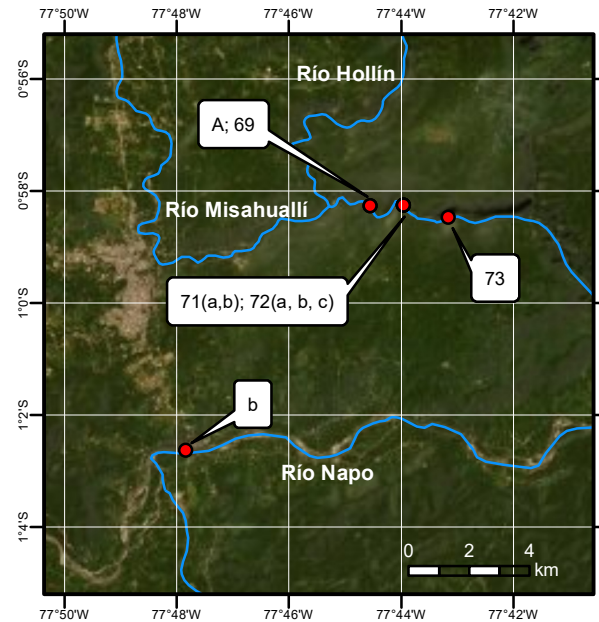
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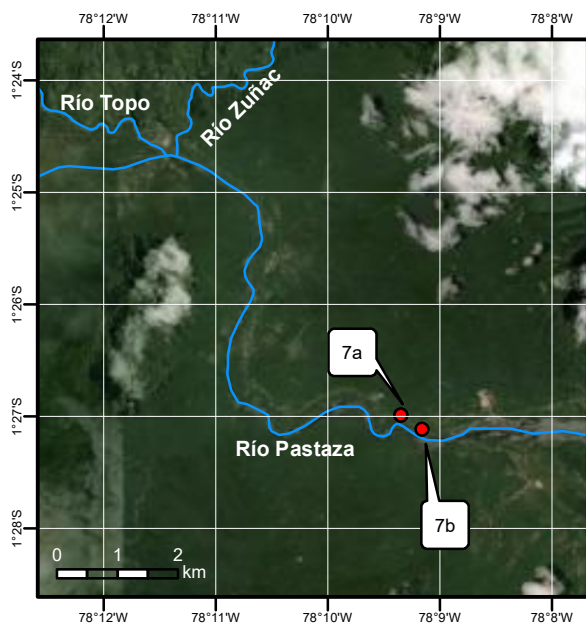
Section 2. Río Papallacta, Río Cosanga, Río Quijos



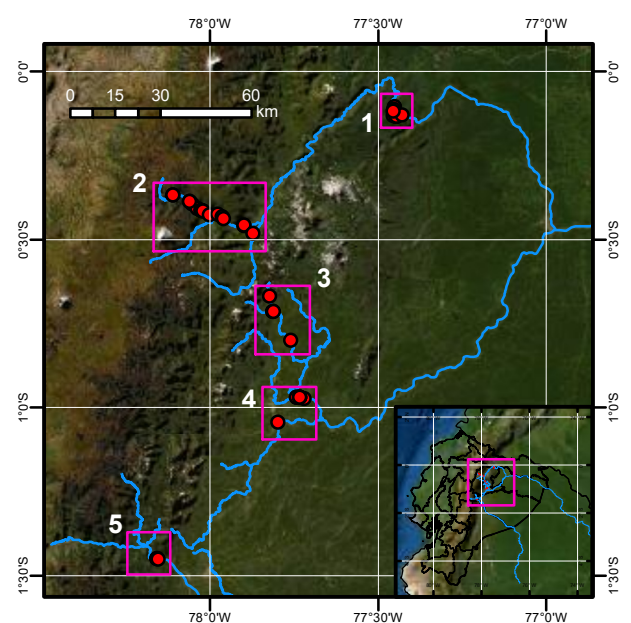
Section 3. Río Urcusikuyacu, Río Jandache, Guacamayos Mt.



Section 4. Río Misahualli, Río Napo



Section 5. Río Pastaza, Río Topo, Río Zuñac



Sections' location

[American Geographical Society, Geographical Review, Vol. 22, No. 4, pp. 677-678]

ERUPTIONS OF THE VOLCANO TUNGURAHUA IN ECUADOR

by

JOSEPH H. SINCLAIR

The beautiful snow-capped volcano of Tungurahua stands on the eastern slopes of the Andes, some fifty miles south of Cotopaxi. An interesting description of its eruptions, which are among the greatest known in Ecuador, has been written by Nicolás G. Martínez, of the observatory of Quito ("Las grandes erupciones del Tungurahua de los años de 1916-1918", Quito, 1932). The first eruption of which we have reliable historical proof was that of 1773, after which the volcano was dormant till the great eruption of 1886. After this with the exception of emission of decreasing amounts of gases, the volcano was quiet till March 3, 1916, when it suddenly broke out in violent eruption. The eruptions continued till March 11 and after nearly a month of rest a final eruption took place on April 13. No further eruptions took place till January 5, 1918. On February 10, March 15, April 5, May 18, June 25, and November 16, 1918, violent eruptions took place.

Martínez describes the phenomena, which he personally observed during the eruptions of 1916 and 1918, and especially the *nubes ardientes* (fiery clouds) which he states were first noted by him in Ecuador, subsequent to Lacroix' discovery of the phenomenon (*nuée ardente*) at Pelée in 1902. He believes that this phenomenon has occurred in previous eruptions in Ecuador but has not been recognized, being confused with the effects of true lava streams.

Ash from the March 16, 1916, eruption of Tungurahua fell as far as the Pacific Ocean, 240 kilometers distant. Martínez calculates the amount of ash that fell during this eruption in the province of Tungurahua alone at 26000000 cubic meters.

